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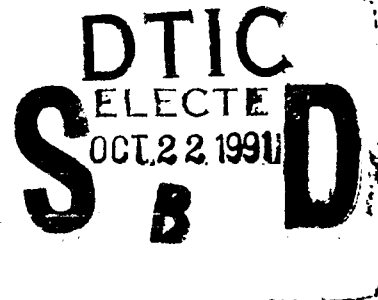


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Computer-Aided Engineering (CAE)  
Tool Assessment/Development

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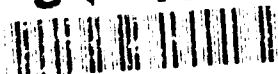
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## 1 INTRODUCTION

The spacecraft designer faces a number of significant challenges that are unique to his field. The spacecraft designer must account for environmental rigors that are either unknown or insignificant at the earth's surface. In addition to creating a component or system to perform a specific function, the spacecraft designer must ensure that it will operate properly in the hostile space environment. The system must be thoroughly checked out to verify that it will survive and operate successfully in space -- that the many possible interactions between the spacecraft and its environment are each either suppressed or made benign.

To perform this process of design verification, the orbit in which the system or component must be characterized. This characterization may require the utilization of many models and analyses, and generally consists of a tedious, complex series of iterations. In many cases, the designer makes strong assumptions about a particular interaction or set of interactions because an adequate model may not be available. Such assumptions may lead to failure of the component. If a wrong assumption is discovered after being built into the design, it can necessitate expensive redesign and rework.

Even when the designer does have the necessary models and analytical tools available, they are generally disjointed and require the running of one model or analysis whose output feeds into another. Subsequently, when the designer has run the necessary analysis or set of analyses, the results must be fed back into the design process, and the system modified or further developed to account for deleterious effects that have been discovered. The designer must reiterate the analysis to verify the modified design. This process is very time-consuming and inefficient, as well as error prone.

One solution to this problem is to develop integrating CAE tools. Ideally, these should provide a convenient and efficient means for the designer to investigate the various regimes of environmental interactions to which the system will be subjected, and also tie directly into the engineering design tools. Very little work has been done in this area. ESABASE is one example of a system which brings together environmental analysis and engineering design CAE tools. Another example is the EPSAT system developed by S-CUBED for NASA. EPSAT combines a large number of computer models within a single user interface, and the final EPSAT tool will be used to perform engineering tradeoff studies of spacecraft power systems and their interactions with space environments.

The special considerations of the spacecraft designer may be categorized as mechanical, thermal, electric, electromagnetic, and chemical. These areas must be considered in terms of for functionality within the system and in terms of deleterious as well as benign and constructive interactions with the surrounding environment. Some of the different relevant interactions are discussed in Appendix A.

When designing costly space systems, it is essential that the designer have adequate and accessible tools to ensure that the spacecraft design will perform in the orbital environment and will have the required orbital lifetime. Additionally, the design must be cost-effective, both in terms of the actual delivered spacecraft system and in terms of the

The project was divided into two phases. The first phase was to design and execute a survey to determine the types of CAE tools in use, the computing environments in which they are used, and what types of CAE tool developments are needed. The second phase was to investigate ESABASE, and to evaluate it as a possible prototype for a future integrated CAE tool system to be developed. The project was conducted from September 1989 through September, 1990, and this final report is a summary of the results of the activity.

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## 2 APPROACH

### 2.1 CAE SURVEY

The objectives of this phase of the project were to identify the CAE tools in use by spacecraft designers and analysts, how they are being used in the spacecraft design and analysis process, what sort of computing environment the tools are being used, and what type of future developments are considered most desirable. These objectives were met by the design and execution of a survey of experts in spacecraft design and analysis, and discussion of the technology with experts.

#### 2.1.1 The Expert List - Survey Recipients

A list of 175 experts in the area of spacecraft design and analysis was assembled. These experts included those involved both in the use and design of the tools used by the spacecraft designer and analyst, and covered universities, government and industry. It was believed that these experts would provide a broad base of the latest information on the use of CAE tools in spacecraft design and analysis. The expert list is included as Appendix C.

The main device for obtaining information from the experts was a survey questionnaire. The questionnaire is briefly described in the next section.

#### 2.1.2 The Survey Questionnaire

The survey questionnaire (included as Appendix B) contained eight main sections. These eight sections are identified in the following sub-paragraphs.

##### 2.1.2.1 *Section I - Personal Information*

This section solicited information on the address and employer, as well as the job function of the respondent. This section was identified as "optional," to allow the person to respond anonymously if desired.

##### 2.1.2.2 *Section II - Position on Addressing Environment Factors Early in the Design Phase*

This section asked for the respondents position on the importance of addressing environmental factors early in the satellite design phase. The response to this section was considered to be important in determining the perceived utility of integrated CAE tools in the spacecraft design and analysis field.

#### 2.1.2.3 *Section III - Factors in Choosing a CAE Tool*

This section sought to determine the ranking of the various factor used to choose a CAE tool or analysis program. The factors treated included: price, product support, application assistance, computer platform, capability, and documentation.

#### 2.1.2.4 *Section IV - CAE Tools/System Analysis Programs*

This section investigated the various CAE tools and analysis programs actually in use. Both commercial and in-house-developed programs were addressed. In addition to the identification of tools in use, information about the interface and input/output characteristics was sought.

#### 2.1.2.5 *Section V - Commercial CAD/CAM Software*

This section sought to determine which CAD/CAM tools are in use at the facilities of the respondents. This information is important in evaluating the utility and adequacy of the interfaces between the various programs in use and in identifying possible future interface development.

#### 2.1.2.6 *Section VI - Tools Aware of, but Not Used*

This section sought to identify those tools and programs that the respondents are not currently taking advantage of, and to determine the reasons for this. This section solicited an "essay" response, to allow the respondent to explain the reason for a particular tool or program's not being used.

#### 2.1.2.7 *Section VII - Computing Environment*

This section was to determine the type of facilities available to the respondent in performing the spacecraft design and analysis functions. This information is important because in many cases, the sophistication of the tools that can be used are limited by the computing resources of the user, and this must be considered in identifying future CAE developments.

#### 2.1.2.8 *Section VIII - Future CAE Tool Development*

This section solicited the respondent's opinion on what type of developments should be pursued. This information is important because any developments must be perceived to be useful by the user community to be credible and to be used by them.



## 2.2 ESABASE CRITIQUE

The objective of this phase of the project was to investigate ESABASE as a prototype for future integrated CAE tool system development. The investigation included familiarization with ESABASE from the user standpoint, visits to ESTEC where the ESABase is maintained and to MATRA/ESPACE where ESABASE is used by an industry design/analysis group, study of the manuals and documentation for ESABASE, and running of test cases on ESABASE. The criteria used to evaluate ESABASE during this investigation are included as Appendix D.

### 3 SURVEY RESULTS

The survey was sent to the 175 people identified as experts in Appendix C. 52 responses were received. The details of the responses are given in the following sub-paragraphs.

#### 3.1 SECTION I - PERSONAL INFORMATION

The distribution of professional backgrounds of the respondents is shown in Figure 1. 41.5% of the responses were from persons directly involved in design and development, and 30.2% were from those in research and development. The remaining responses were roughly uniformly distributed among project management, quality and test, systems and software, and "other."

#### 3.2 SECTION II - POSITION ON ADDRESSING ENVIRONMENT FACTORS EARLY IN THE DESIGN PHASE

The distribution of responses to the question "How do you feel about addressing environmental factors early in satellite design?" is shown in Figure 2. 66.7% of the respondents indicated that it must be done. An additional 28.9% indicated that it should be done. Thus, two-thirds of the sample community say that it is absolutely necessary to address the environmental questions early in the design phase. and only 4.4% feel it is not mandatory.

#### 3.3 SECTION III - FACTORS IN CHOOSING A CAE TOOL

Figures 3 through 9 detail the responses to the inquiry concerning the importance of price, product support, application assistance, computer platform, product capability, and documentation, respectively in choosing a CAE tool or system analysis program.

Figure 3 summarizes the responses for all six criteria. The interesting observation from this collective distribution is that with the exception of product capability, none of the factors is considered superordinately critical. While the critical importance of product capability is expected, it is surprising that such factors as price are not considered critical.

Figure 4 shows the response distribution for price. Almost 20% of the respondents gave price a minimum importance, while only about 5% gave it a highest rating. The maximum response was for a rating of 4 out of 6 on the importance scale from over 25% of the respondents.

Figure 5 shows the response distribution for product support. Product support is considered important by the respondents, with a strong peak in the responses at 5 out of 6 importance rating.

Figure 6 shows the importance of application assistance to the respondents. Clearly, it is considered an important factor, but not a critical one, with the maximum response at 4 out of 6 importance rating.

Figure 7 indicates that the computer platform that the package requires is an important factor, with the maximum response at 5 out of 6 importance rating.

Figure 8 shows the expected result that the package capability is the most important factor in the view of the sample community. This result is not surprising as the main criterion for judging any tool is generally "What can it do?"

As shown in Figure 9, documentation is considered an important factor in choosing a CAE tool, with a maximum response of 5 out of 6 importance rating.

### 3.4 SECTION IV - CAE TOOLS/SYSTEM ANALYSIS PROGRAMS

Figures 10 and 11 show the response distribution with respect to the CAE tools actually used by the sample community. Figure 10 addresses commercial packages. Interestingly, the least-utilized packages are in debris impingement and surface chemistry, two areas that are still often relatively neglected in spacecraft design and analysis. Additionally, these areas are those in which the models available are the least-well developed, so that the development of a successful commercial package is more difficult than in the other areas. Figure 11 shows that a significant number of packages used in spacecraft design and analysis are developed in-house, even in those areas such as mechanical and thermal, in which many recognized analysis packages are available.

Figures 12 through 18 detail the features of the commercial CAE packages in use by the sample community. Concerning the dimensionality of the models used with the packages, three dimensional models are significantly available only for thermal, spacecraft charging, and mechanical packages; while time-dependence is dominant in thermal, EMC, spacecraft charging, and "other" applications. Standard CAD/CAM input to the packages is broadly spread among the commercial packages, with the exception of surface chemistry (for which there was only one response, dictating a 0% or 100% characterization) and debris impingement, which showed zero standard input. Graphic output (Figure 14) is significantly available across the board, supporting the generality that "one picture is worth a thousand words" for spacecraft design/analysis. With the exception of debris impingement all the areas show capability for input to standard post-processing packages (Figure 15). Figure 16 shows the extent that the commercial CAE packages are used in the design/analysis process. (note that the 100% usage in surface chemistry is due to one respondent.) Otherwise, the response is as expected, with a high percentage of "always" responses in the mechanical, EMC, radiation dosage, and thermal areas; which are historically the most emphasized areas in spacecraft design. In debris impingement and spacecraft charging, the tendency is to be used "often" or "when required." Figure 17 encouragingly shows that the commercial packages are used throughout the spacecraft design/analysis process, with significant

application in the conceptual and preliminary design phases. The one respondent in surface chemistry uses the analysis tool in the conceptual phase. Figure 18 shows the training considered as required of use of the commercial packages. As expected, the respondents indicated that all the packages could be used by a B.A. Surprisingly, a significant fraction of the respondents considered training at the Ph.D. level to be need for the mechanical, radiation dosage, debris impingement, spacecraft charging, EMC, and thermal applications.

Figures 19 through 25 detail the features of the in-house CAE packages reported. Concerning the sophistication of the models used with the packages, 3-dimensionality and time-dependence is a significant factor in all the package areas. Standard CAD/CAM input (Figure 20) is significantly available with the exception of debris impingement and surface chemistry. As expected graphic output (Figure 21) is significantly available in all the areas design/analysis. Input to post-processing packages (Figure 22) is missing in surface chemistry and EMC/EMI for the in-house packages. Figure 23 indicates that the in-house packages are used to a significant extent, ranging from "when required" to "always." The in-house packages also are used throughout the design process (Figure 24), beginning with the conceptual design phase. As with the commercial packages, the responses (Figure 25) indicate that the in-house packages in all areas can be used with B.A.-level training, and once aging the respondents indicated that Ph.D.-level was required significantly in the mechanical, radiation dosage, debris impingement, spacecraft charging, EMC, and thermal areas.

### 3.5 SECTION V - COMMERCIAL CAD/CAM SOFTWARE

Figures 26, 27, and 28 show the responses with respect to the CAD/CAM software used by the sample community. Figure 26, shows that as expected, the bulk of the CAD/CAM packages in use are mechanical design packages, since this was the first area in which such software was developed. However, the respondents also use CAD/CAM in circuit design, printed circuit board design, and configuration control. Exchange of data with other CAD/CAM packages is available in all the areas as shown in Figure 27. Figure 28 shows the responses with respect to the standard CAD/CAM output formats available. The responses were sparse, and considered insignificant. However, this demonstrates the fact that the users are not interested in the technicalities of transfer formats, and emphasizes the need for transparent interfaces.

### 3.6 SECTION VI - TOOLS AWARE OF, BUT NOT USED

The responses to this question are included in Appendix E.

### 3.7 SECTION VII - COMPUTING ENVIRONMENT

Figures 29 through 32 illustrate the responses about the current computing environment available to the respondents. Figure 29 shows that VAX (35.6%) is the dominant environment. Additionally, 35.6% of the respondents reported that they use

"other" computing environments. Of these reported other environments, 47% were reported as IBM PC's. 20.8% reported Apollo or Sun. and 7.9% use Crays. Figure 30 illustrates the distribution of networks accessed by the sample community. 41.1% report that they are on VAX-based networks (SPAN and DECNET). Figure 31 shows that the operating systems used are roughly evenly divided among VMS (29.6%), MS-DOS (30.9%), and UNIX (38.3%). Figure 32 shows that the graphics capability both of the hardware and system software used by the sample community are rich in capabilities.

### **3.8 SECTION VIII - FUTURE CAE TOOL DEVELOPMENT**

Figures 33 through 37 show the responses about what developments the respondents consider valuable. Concerning the development of a CAD/CAM modeler combined with an analysis tool, Figure 33 shows that 48.7% consider this very important, and 43.6% consider it important. Concerning the development of a 386i or workstation-based back-of-the-envelope spreadsheet type program, (Figure 34), 36.8% consider this very important, and 34.2% consider it important. 50.0% consider it very important to develop a user-friendly screen-oriented front end tailored to specific analysis codes (Figure 35), and 37.5% consider it important. 30.8% consider it very important to develop an integrated CAE tool in which all the analyses can be performed (Figure 36), while 43.6% consider it important. As shown in Figure 37, 44.2% of the respondents indicated that they would like to see an integrated CAE tool package developed, and 34.6% said they would like to see concise explanation of the science incorporated.

## 4 ESABASE CRITIQUE

As part of the "Computer-Aided Engineering (CAE) Tool Assessment/Development" contract, the ESABASE package was examined as an integration framework for spacecraft/environment interaction analysis programs. The ESABASE framework (or ESABASE) was developed by the European Space Research and Technology Centre (ESTEC) (Noordwijk, The Netherlands) of the European Space Agency (ESA) and Matra-ESpace (Toulouse, France). The ultimate goal of this critique is to learn information which will be useful in designing a CAE tool to perform engineering level analysis of spacecraft/environment interactions to ensure successful mission performance.

In order to maintain the required quality and software controls necessary for a package such as ESABASE to be successful, access to the source code is restricted to the package developers and maintainers. While ESABASE is not readily available for making modifications and enhancements, it does provide some useful insights into the problems and solutions of integrating analysis codes into a single framework. ESABASE also demonstrates the benefits of a standardized analysis package.

### 4.1 DESCRIPTION OF THE STANDARD VERSION

One of the major goals of ESABASE is to provide a standardized spacecraft model and a uniform set of interaction analysis codes to allow communication between the different groups involved in ESA projects. Since all of the interacting groups use the same version of ESABASE, spacecraft models are transportable between sites. Also, all analysis calculations are performed using the same programs. Using a standard set of analysis codes is helpful, because even if the codes are not the best available, everyone knows what calculations design decisions are based on and they can reproduce them if desired. Continuing development also benefits from standardization, since ESABASE provides a stable and tested development environment for new utilities and analysis programs.

The purpose of the ESABASE framework is to integrate existing analysis programs, not to rewrite or extensively modify any old codes. This approach forces the package to allow for different object geometries for some of the analysis codes. Therefore several parallel definitions of the same spacecraft are often necessary.

ESABASE consists of a framework, generally useful utilities and tools to used to define the spacecraft, and a group of application programs used to analyze the spacecraft. The framework includes the user interface (menus, forms, and editors tailored to help the user define objects and set up the input files for the analysis programs), postprocessing capability, a database manager (which translates and checks the ASCII version of the spacecraft system file and can extract specific information from the database upon request), and tools for orbit generation, pointing and articulation control, and environment (radiation, atmospheric, and solar) definition. There are also visualization utilities which display the 3-D spacecraft and results from analysis calculations.

ESABASE defines spacecraft systems using a hierarchical object definition. A database file contains a single system. Each system is composed of a number of subsystems and/or objects. The objects are related in a parent-child manner. The relationship between the components in a system (the configuration) can be manipulated. Additionally, each object can be defined to have several states (for example, a tank could be empty or full). At the lowest level of detail, attributes such as shape or material definition are assigned to components of the system. At the higher levels, relational information is defined. Specific properties of objects required for the different analysis applications are defined at the lowest necessary level.

While the object definition is not totally general, the shapes recognized by the database are more than sufficient to define most problems. Geometric objects are defined several different ways due to the input expectations of the different analysis packages. The standard spacecraft definition uses a solid model description. The thermal analysis requires a surface boundary representation. Both definitions are maintained in parallel in the same database file (a solid shape definition and a surface representation for each object), so it is fairly convenient to define the models. The NASCAP building block object definition required to perform surface charging analysis is kept outside of the main ESABASE program.

The application packages currently available via ESA or other sources can analyze mass and balance, thermal, radiation, surface charging, and EMC issues. There are also applications available for studying the electrical harness configuration, plume effects, field of view occultation, orbital perturbations due to environmental effects, atomic oxygen effects, and attitude and orbit control.

There are a number of other packages which can communicate with ESABASE. Postprocessing data from ESABASE can be done using most of the major CAD/CAM and display programs. EUCLID is able to generate ESABASE input using a restricted menu/user interface or by using the general solid definitions and only translating items which have an ESABASE equivalent. This interface is maintained by EUCLID for ESA. CATIA is also able to create ESABASE objects, but is not presently commercially available.

When ESABASE is run, a script file (a file containing operating system commands) controls the execution of the different analysis and support programs. When an analysis program finishes its task, control returns to the system command file. This is a handy way to keep from having to link all of the framework and application programs together in one huge program. Each executable reads commands from either the user interface or from its standard input file. Because the package is not controlled by compiled coding, existing programs to be can be joined together with few or no modifications once the program can use the ESABASE database.

The ESABASE coding is implemented in clearly written and consistently used Fortran. The coding is well commented in English. The package was written originally for a VAX/VMS environment, but the few system dependent parts of the code have been rewritten to make porting the code to another machine fairly straightforward. The exception to this is that the user interface relies on the VMS screen management utility. There are plans to change to a more general screen handler, but this has not happened yet. On the other hand, the coding can be modified to not use the screen handler and to treat all input terminals as dumb ASCII terminals. This has allowed the functionality of ESABASE to become available on UNIX based computers (which do not have the VMS screen manager) without the full screen interface. The documentation available for ESABASE users is also clear and thorough.

The ESABASE package is available upon request to ESTEC for no charge to ESA members. There is one reduced installation of ESABASE in the USA at Goddard. ESABASE is distributed in compiled form ( without source code, for quality control reasons) along with the documentation. Applications which are not provided with ESABASE, must be obtained from ESA or other sources. ESTEC performs all the maintenance and support tasks for the software it distributes.

After twelve years of development and use, the experience of the ESABASE developers and users has been positive. ESABASE is successfully used within the ESA community. The unified package provides a common analysis language to pass models between a diverse group of project participants. As people use it more, they are starting to transfer information from group to group via ESABASE. In fact some ESA contracts require maintenance of ESABASE models and databases. The use of common, standard applications means that no matter how bad the models are, the community knows the limitations of each of the analysis programs. The opposite situation is where each company has its own set of proprietary analysis codes which are not usually well known or understood by the rest of the community.

When integrating different analysis codes, the main problem of transferring data between the codes arises from the way the spacecraft model is represented inside each particular code. Defining a unified model allows enhanced interplay between groups of codes. It also offers a convenient way for analysis code designers to interact while creating a package useful for the end users, the spacecraft designers.

New analysis applications are built with the package since it provides a ready made development environment. Any analysis packages which are in some way deficient or nonexistent are added by specific projects as required, but once they are added to the ESABASE package they can be used again later. This is true both for tools developed for in-house purposes and those developed expressly for inclusion into the standard package.

Future development directions for ESABASE include improvements in the user interface, the analysis models, and the database. In order to allow access to a wider set of



computers, there are plans to complete the port from VMS to UNIX by using a UNIX oriented screen interface (probably curses or X11 based). To help the user define spacecraft and their attributes, a menu/form driven object definition tool may be developed.

Analysis applications improvements are where the bulk of the development will occur. More applications will be integrated. The existing model will be improved or replaced with faster models. These new codes will include the ability to perform dynamic calculations. The practice of designing reusable software, such as the ray tracing tool, will encourage new and faster methods to solve problems. There is also a trend to incorporate quick, order of magnitude calculations in addition to the existing detailed 3-dimension computations presently available. This allows the users to perform tradeoff studies to determine which of the slower calculations are necessary. Some times a quick estimate is all that is really required.

The database portion of the framework is also undergoing improvements. System-A (MatBase), under development at Matra, will allow increased data interchange between analysis modules. The present form of ESABASE integrates disparate codes by combining them under a common user interface, unifying postprocessing tools, and providing some common analysis functions (such as orbit generation and environment definition) to each of the applications. Improvements in the database portion of framework are aimed towards allowing different applications to interchange results. Integrated different analysis codes supports an increasingly sophisticated level of spacecraft/environment interaction analysis.

## **4.2 ASSESSMENT OF ESABASE AS AN INTEGRATION FRAMEWORK**

The major success of ESABASE is the creation of a standard for the interchange of spacecraft design analysis information. By defining both the spacecraft definition and accepted analysis applications, ESABASE enables communication between scientists developing analysis codes, spacecraft design engineers, and the sponsoring organizations. The end result is more reliable and efficient spacecraft design. The integration framework defined by ESABASE is the common language to be used for the communication.

ESABASE provides a well defined input language and a number of utilities for postprocessing which are a benefit to the code integrator. An existing user interface package is also available to developers who wish to add one to their programs. The system definition language is powerful, but since definitions are written by hand by the user, getting the most out of system description relies heavily upon the skill of the ESABASE user.

The ESABASE solution is an evolving one and there are some areas where improvements are possible. Presently, not all applications can use the same spacecraft descriptions. It would be helpful to be able to use existing CAD/CAM design tools, which are designed to construct geometric objects, to generate suitable input for spacecraft/environment interaction analysis. In many cases, a spacecraft definition may already exist for another CAD package. The main problem is the level of detail from

typical CAD programs is higher than is appropriate for analysis. Another common integration problem arises when an existing application package is not able to use a general, finite surface element definition of a spacecraft. This happens primarily with the analysis codes which were developed independently and restricted geometries used.

Another area where the package is presently evolving is in the data exchange between the analysis packages. The work on quick estimating tools at ESTEC and more intelligent databases at MATRA are the first steps in this direction. Quick estimates of values will add a new function for the user which expand the usefulness of ESABASE. Analysts will be able to study interactions involving more effects. Rather than performing a calculation with several modules in parallel, it will become feasible to study combined effects in complex systems. The combination of the two improvements will enable the designer to determine which sets of spacecraft/environments interactions are important for a particular system. Using this information, the more detailed calculations can be performed as needed.

### 4.3 CONCLUSION

In its present state, ESABASE provides the integration framework necessary to put together existing analysis codes without extensive modifications. The system definition files are designed so the additional information which may be required by a new application can be included without affecting the all of other applications. The integrator also has a number of tools for designing a consistent user interface, graphics programs and so on. Even if the new analysis program is unable to communicate with any of the other applications, it will have a similar interface.

Future improvements, which impact integration issues, are primarily planned in ESABASE database. As more of the older analysis codes are modified to couple more tightly with framework, they will be able to interchange data with other analysis packages. As ESABASE becomes more widely used for development, new applications will be able to reuse the supporting framework code and focus on the analysis functions.

The adoption of ESABASE as an integration framework for USA applications may be possible but it presents some logistical problems. First of all, an agreement with ESA would be necessary to import the package. The present package is only distributed as compiled code on VMS machines (though it will probably be available for other operating systems before too long). In order to keep the level of quality control required to remain a useful standard, it is difficult to obtain the source code for the framework software. While this tactic prevents unauthorized changes, it also slows the implementation of improvements. Additionally, it is not clear how much user and developer support would be available from ESTEC in the USA (especially on the west coast because of the large time difference).

Some valuable lessons can be learned from the ESABASE project. One is to define a clear set of goals for the desired level of analysis code integration. Then apply the most

pragmatic solution which addresses the issue. Another lesson is that some of the main benefits of an integration package are the definition of a common set standards for spacecraft definition and analysis applications to be used by all groups. In order to serve as a standard, though, a strong quality control assurance must be in place. If everyone is able to make changes or modify the standard set of programs, the different versions of the package will diverge and no longer be useful as a standard.

An implementation should provide a state of the art set of development tools to new code designers. A new framework package should be oriented to integrating new applications, while providing a simple way to integrate existing programs into the package as easily as possible. To get the best long term return from the integration project, the software design should be focused on current and future improvements. Since the status and capabilities of existing programs is well known (or at least knowable), building in the means to bring in older codes is an easier task.

## 5 CONCLUSIONS

Current CAE tools can benefit enormously from the rapid advances in computer hardware and programming techniques. Larger and more complex calculations are possible on today's faster computers. Use of technology advances in operating systems, graphics, and program/user interfaces can decrease the amount of time needed to learn to use the programs while increasing the complexity of the calculation. The falling costs of computing platforms means greater availability of cheap, reliable computing power. It is expected that these improvements will continue over time.

### 5.1 Areas Potentially Needing Improvement

The spacecraft designer approaches CAE tools in the same manner as any consumer evaluates a cost or effort saving device. The CAE tool must help the engineer build a better satellite by being available, inexpensive in terms of manpower or dollar cost, and by being able to perform the tasks necessary to aid the user. The features of these issues are addressed below.

#### 5.1.1 Availability of CAE Tools

If a CAE tool exists, but cannot be delivered to the person interested in modeling spacecraft/environment interactions, the resource has been wasted. One of the major obstacles to availability is incompatibility with the hardware, operating system, or proprietary software tools already in use by the engineer. In order to take advantage of the rapidly changing computer world, CAE tools need to be easy to modify. A target computing environment is necessary to develop and deliver a new or modified tool.

#### 5.1.2 Cost of CAE Tools

The cost of a CAE tool is not just determined by the dollar amount paid to a private company. The issues of training new users and the speed of the calculations also need to be considered. A reduction in the costs to the spacecraft designers of acquiring and incorporating the CAE tool into the design cycle will enhance the effectiveness of the CAE tool.

The use of closed architecture, proprietary commercial software products or hardware configurations prevents the user of a CAE tool from getting the best value for dollars spent. Locking in a particular vendor makes the customer vulnerable to unreasonable costs for purchasing the necessary items. This can be avoided by the use of standardized or open architecture equipment and software.

A reduction in the time required to learn a new CAE design tool also reduces the labor hours cost of using the tool. Integration of codes into an existing framework saves the

time needed to learn a different interface. Use of existing, standard CAD/CAM programs eliminates the need to learn a new one.

### 5.1.3 Usefulness of CAE Tools

To serve its purpose as a CAE tool, the analysis codes within the CAE tool must be reliable. The ability to transfer information from one analysis code to another via a well defined framework increases the usefulness of the tool.

## 5.2 Ways to Enhance CAE Tools

Enhancements which will improve CAE tools can be divided into groups. General improvements are those which increase the ease of use of the tools by providing consistent interfaces and generalized utilities that can be used by a group of analysis and CAD/CAM programs. Some more specific solutions can be suggested to aid the spacecraft engineer during the different design phases.

### 5.2.1 General CAE Tool Enhancements

Improvements in the interface between the user and the design tool, integration of the CAD/CAM program, analysis codes, and post-processing packages, and use of a framework to coordinate the transfer of data between different modules can ease the burden of the design engineer. A standardized screen interface can present uniform commands, such as access to a Help utility or an Undo command, for all of the modules. Prompting the user with menus and forms eliminates the need to remember cryptic keywords or a large set of parameters which must be used in order to run an analysis code.

Another benefit of using a common user interface for all of the different modules is the added convenience of using standard postprocessing tools. Many terminals permit both text and simple graphics, typically emulating a Tektronix 4014. Plotting utilities can be generated once, then used as a library by each of the analysis modules. If an improvement in the graphics library becomes available, the interfaces for each of the modules using the library automatically have access to the new features.

### 5.2.2 Engineering Tradeoff Study Tools

During the preliminary design phase, rapid assessment of interactions of a spacecraft with a large numbers of environmental factors needs to be assessed. A detailed description of the spacecraft may not be available. Rather than perform separate calculations and analysis for each interaction and attempting to piece together the results, a comprehensive tool can be developed which ties the interactions into a cohesive computational tool. A tradeoff study tool cannot replace the more thorough three-dimensional analysis tools for detailed calculations, but it can assist the engineer during the preliminary design phase and target extensive calculations that need to be performed during the critical design phase.

An example of this type of design tool is the EPSAT project. EPSAT provides space power system design engineers with the ability to assess the effects of a broad range of environment interactions on space power systems. It utilizes quick, "back-of-the-envelope" calculations to perform design tradeoff studies. Since EPSAT maintains all of the pertinent data, as well as the methods used to create the data, it is able to act as a sophisticated spreadsheet. If for example, an engineer is interested in the space charge limited currents to an object but only knows ranges of plasma temperatures and densities, EPSAT allows the engineer to set up a table of collected currents versus temperature or density. If the potential on the object is then varied through a range of values by the engineer, EPSAT automatically updates the table or plot of collected currents. If there was some concern with sheath ionization effects, they can be included in the calculation by simply adding a new analysis model. In this manner, new modules are added to existing modules to build on the previous results.

### 5.2.5 Three-Dimension Analysis Codes

For design problems which require detailed, specific geometric information three-dimensional calculations must be used. Typically, these problems arise during the later portions of the design cycle, as the spacecraft details are finalized. Detailed design tools are required for this stage of development.

For the analysis of the final design, presently available technology makes integrated frameworks possible. Within a unified framework the analysis codes access the design configuration database directly, using the most up to date spacecraft definition information. The framework provides a unified database, common object definition tools, graphical output, CAD/CAM translation utilities, simplified maintenance requirements, reduced learning times, and hardware portability.

The general modules can be used by all of the analysis codes. Data exchange between analysis codes becomes possible. And future analysis codes can focus on fewer physical phenomena and use existing, tested and validated analysis models to provide the rest of the data. The framework's modular structure makes it possible to update the package with new or improved analysis codes, CAD/CAM programs, and utilities without impacting the entire package.

### 5.2.4 Turnkey Solution

A possible intermediate solution may be to devise inexpensive, high power CAE toolboxes. This turnkey solution may be useful during the transition of new analysis codes from their development to their integration into a unified package. Currently available portable computers are fast, and have sufficient graphics capability to serve as turnkey analysis tools. The advantage would be that an analysis code, such as NASCAP/GEO, could be moved directly into a personal computer. A 386i based PC, for example, is inexpensive (currently about \$5,000) allows for expandable memory, can be connected to a TCP/IP

ethernet, and utilizes its own hard or floppy disk drives. The resulting system is comparable in computational speed to a VAX 780 and is portable.

Using this type of hardware platform, a simple graphical object definition program could be created to define the small set of NASCAP/GEO building blocks used as calculation input objects. Existing screen oriented user interfaces could be added to simplify input tasks. Present output graphics routines could be used as they are.

Positive advantages to the turnkey CAE toolbox are that it would be an inexpensive and quick way to make analysis tools available to the spacecraft design community as they are completed by the research community. A general toolkit containing user interfacing tools for input, output graphics, and support utilities could be carried from one analysis code to the next. No significant modifications of the analysis codes would be required. Since the analysis code has not been unified with any other modules, integration could become a rather simple process. The same computer could contain several different tools, so there would not necessarily be a proliferation of microcomputers. This technique provides a low risk method of transferring technology from the research community to the engineering community.

The disadvantages to this method are that existing CAD representations of objects could not be used, there is no integration of different analysis tools, and some computationally intensive or large analysis codes may be unable to run on these boxes.

BACKGROUND OF RESPONDENTS

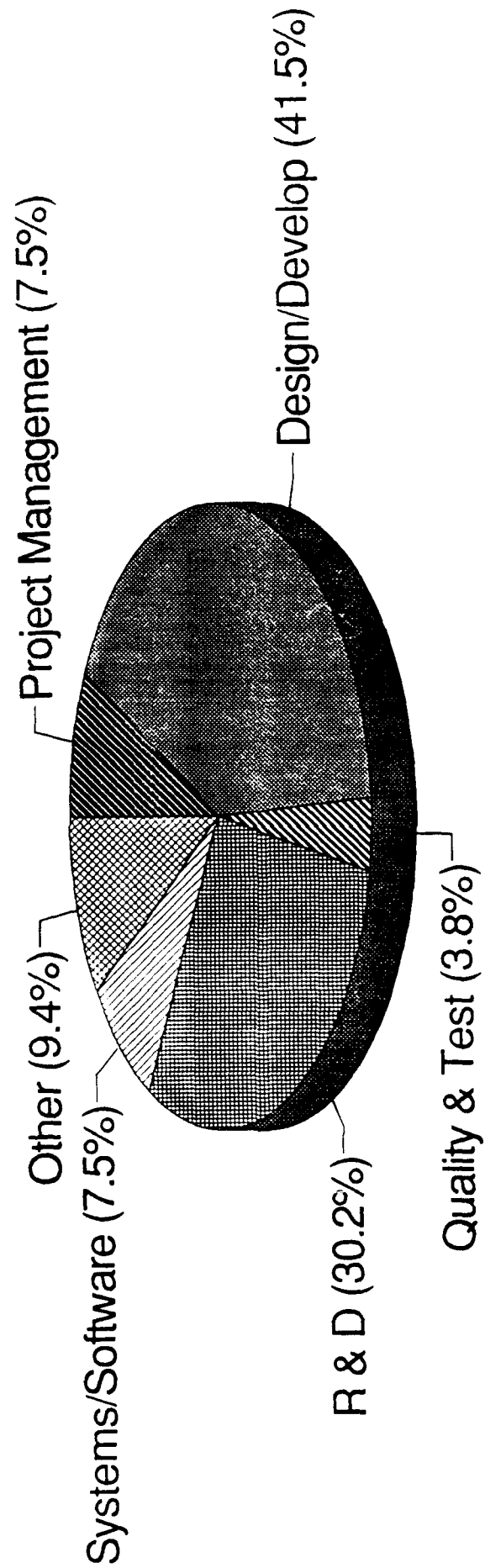


FIGURE 1



# How do You Feel About Addressing Environmental Factors

## Early in Satellite Design?

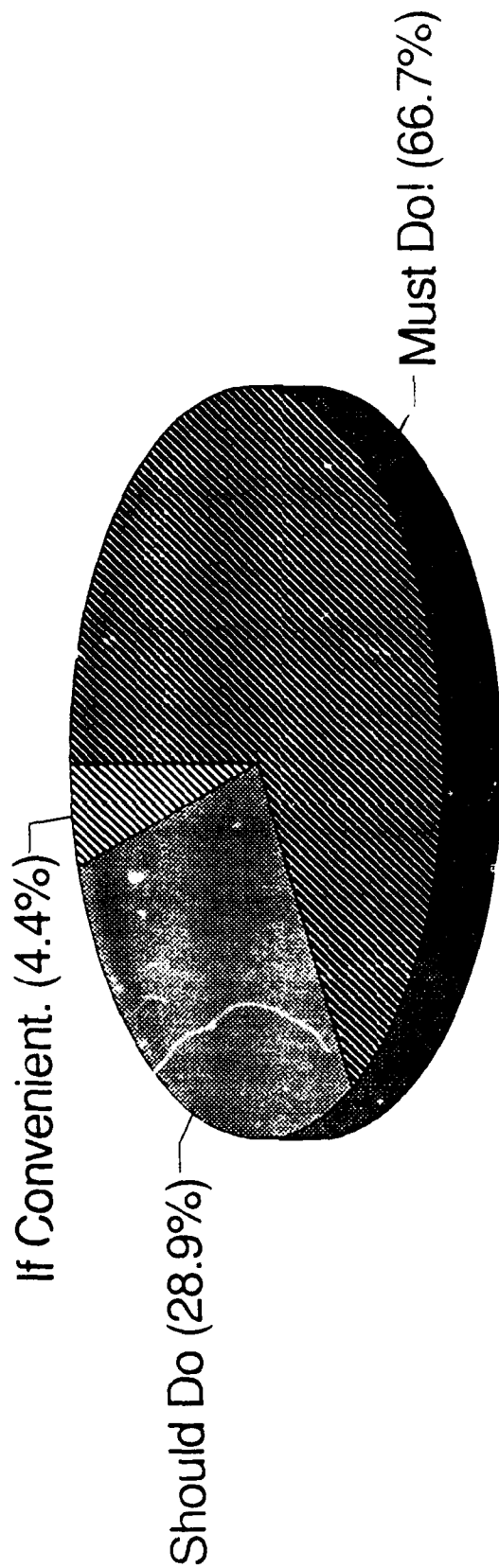


FIGURE 2

What factors are most important in selecting a CAE tool?

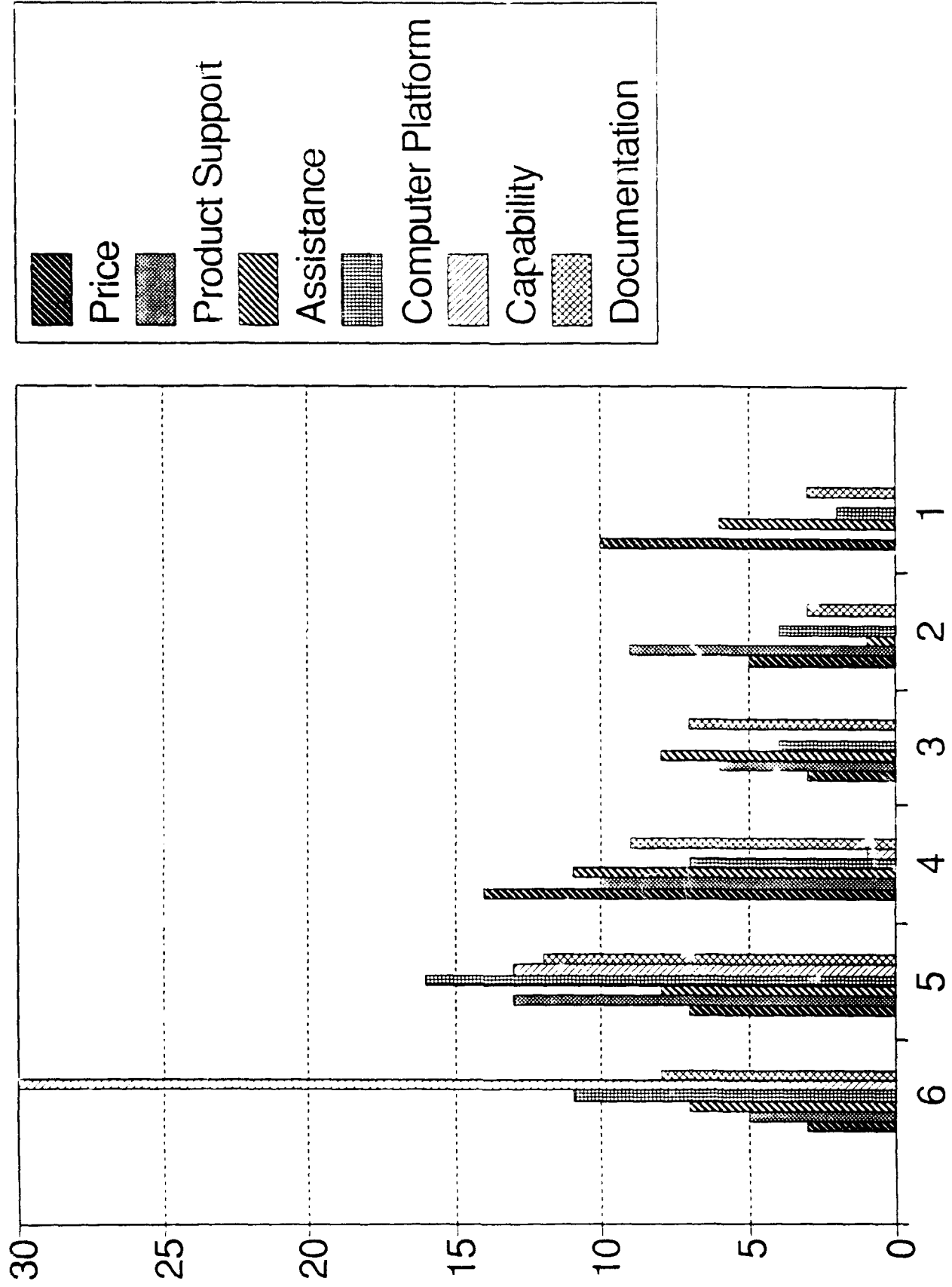


FIGURE 3

# Choosing a CAE Tool

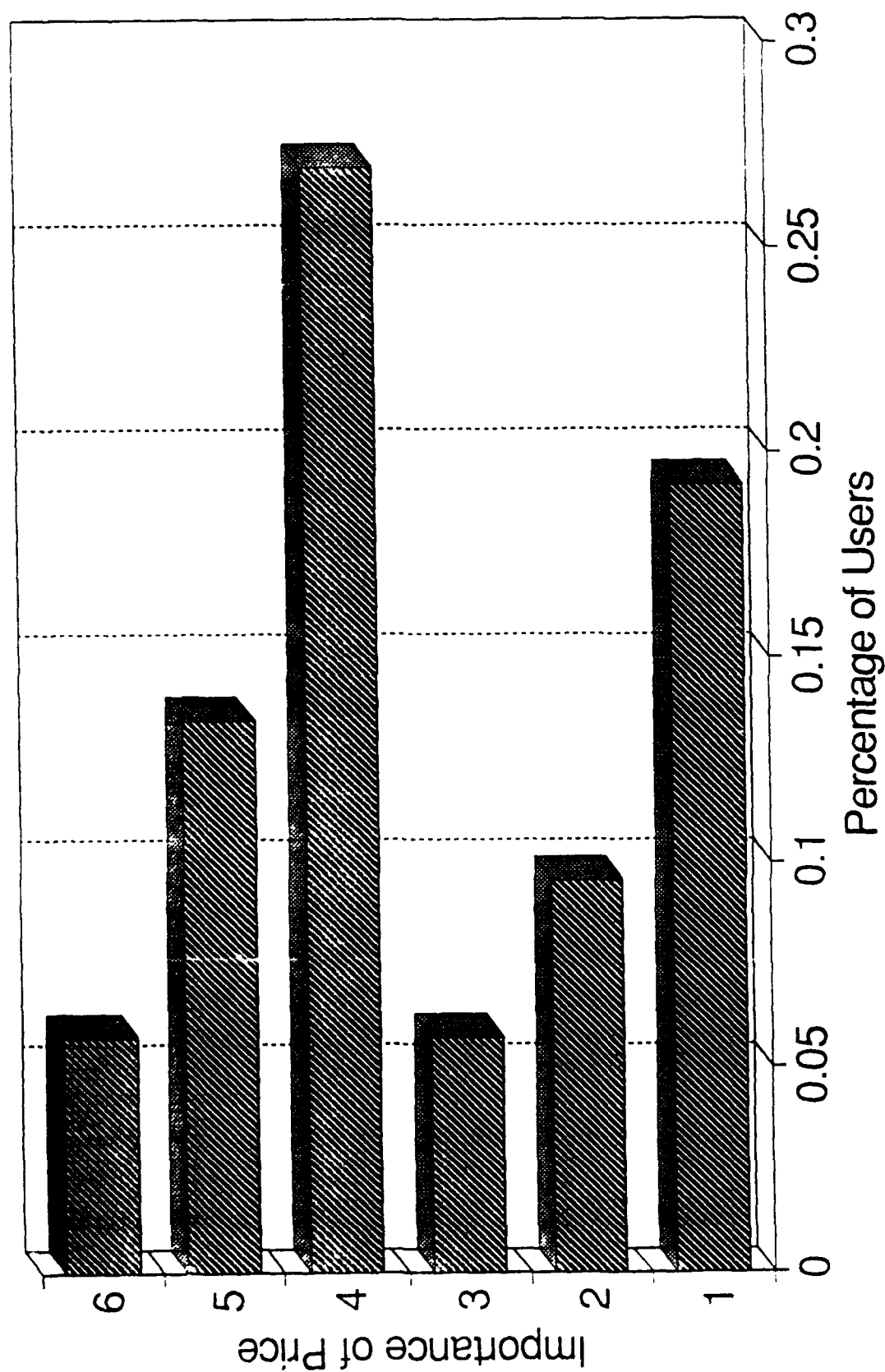


FIGURE 4

# Choosing a CAE Tool

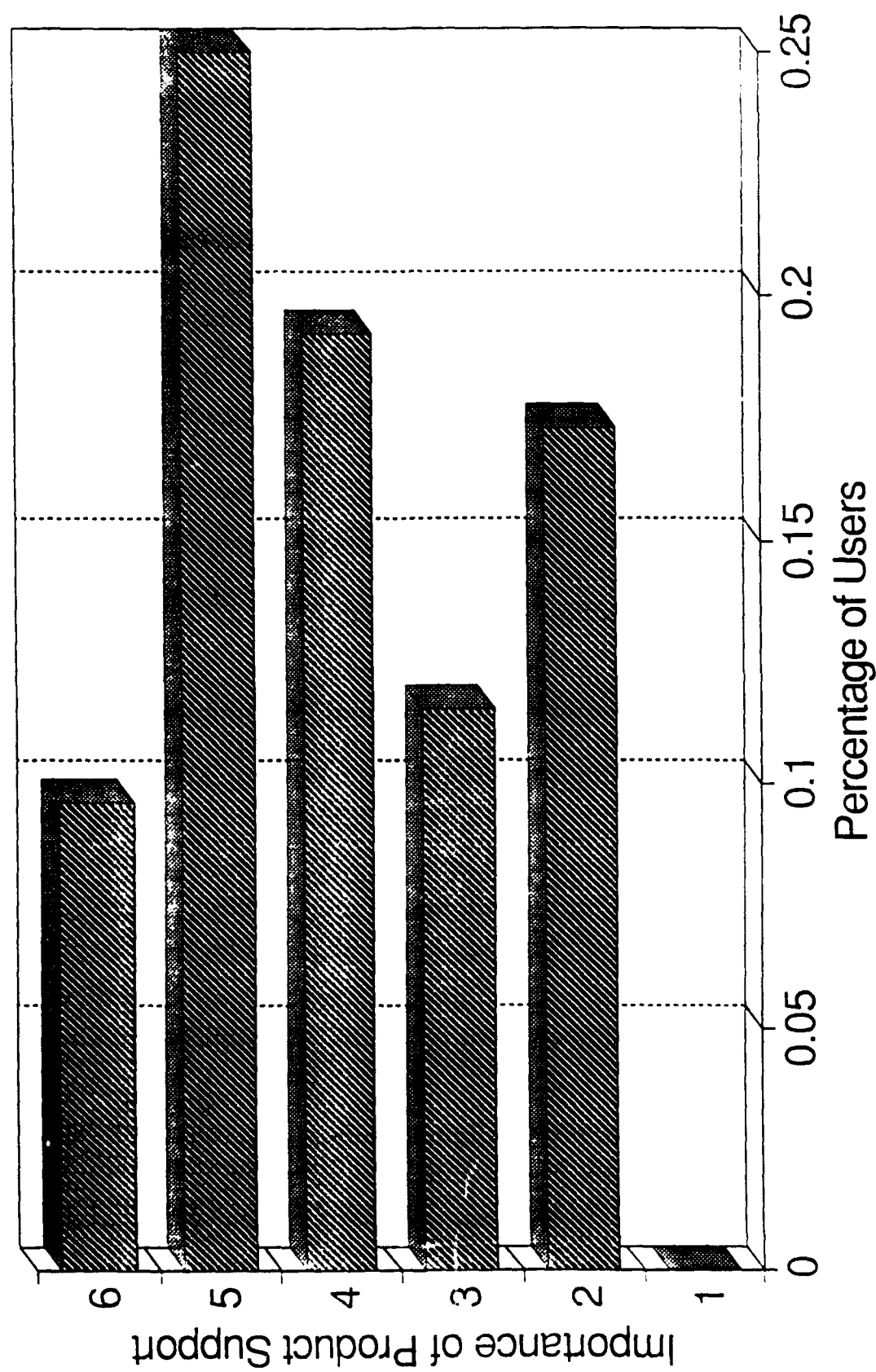


FIGURE 5

# Choosing a CAE Tool

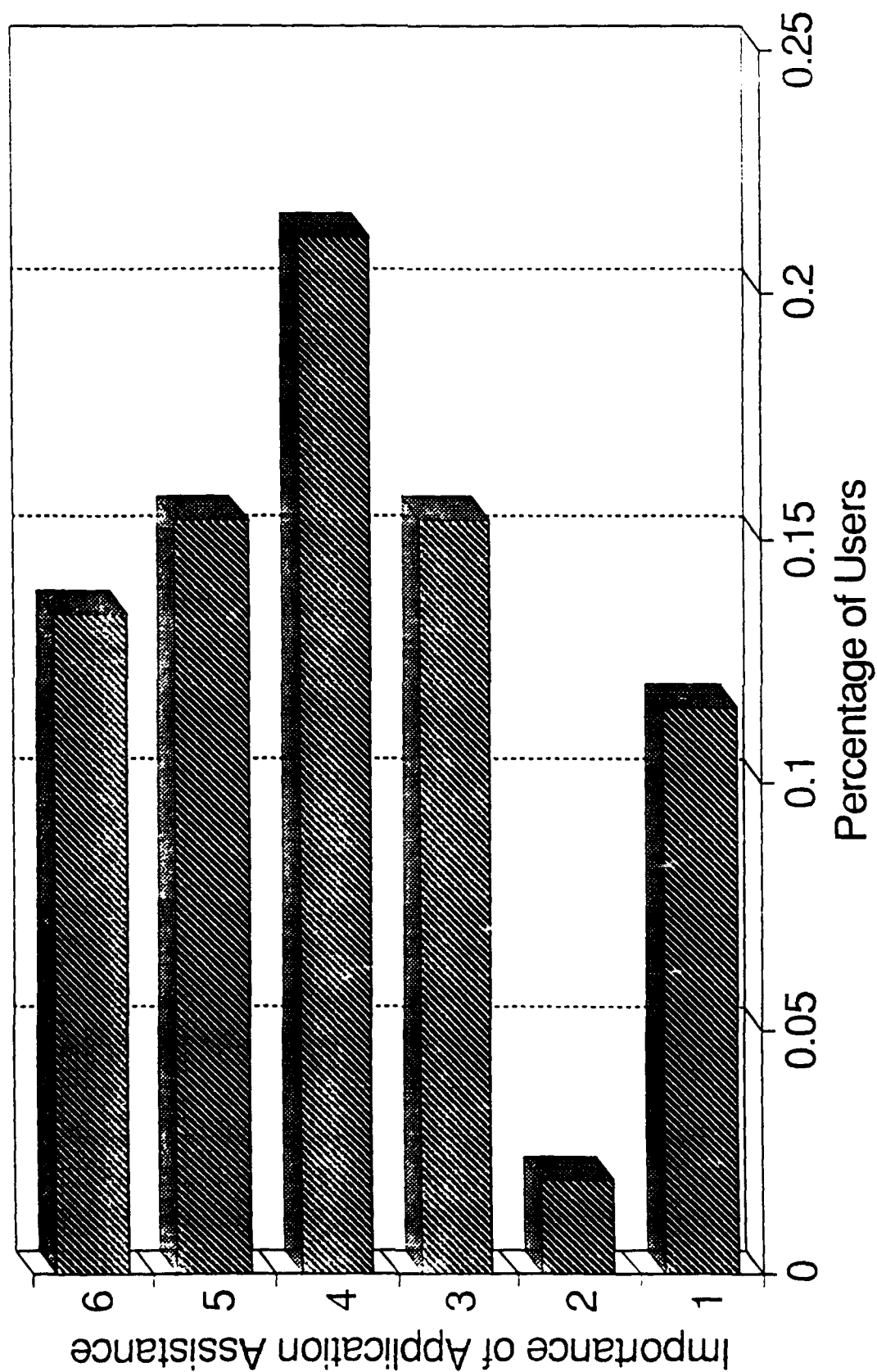


FIGURE 6

# Choosing a CAE Tool

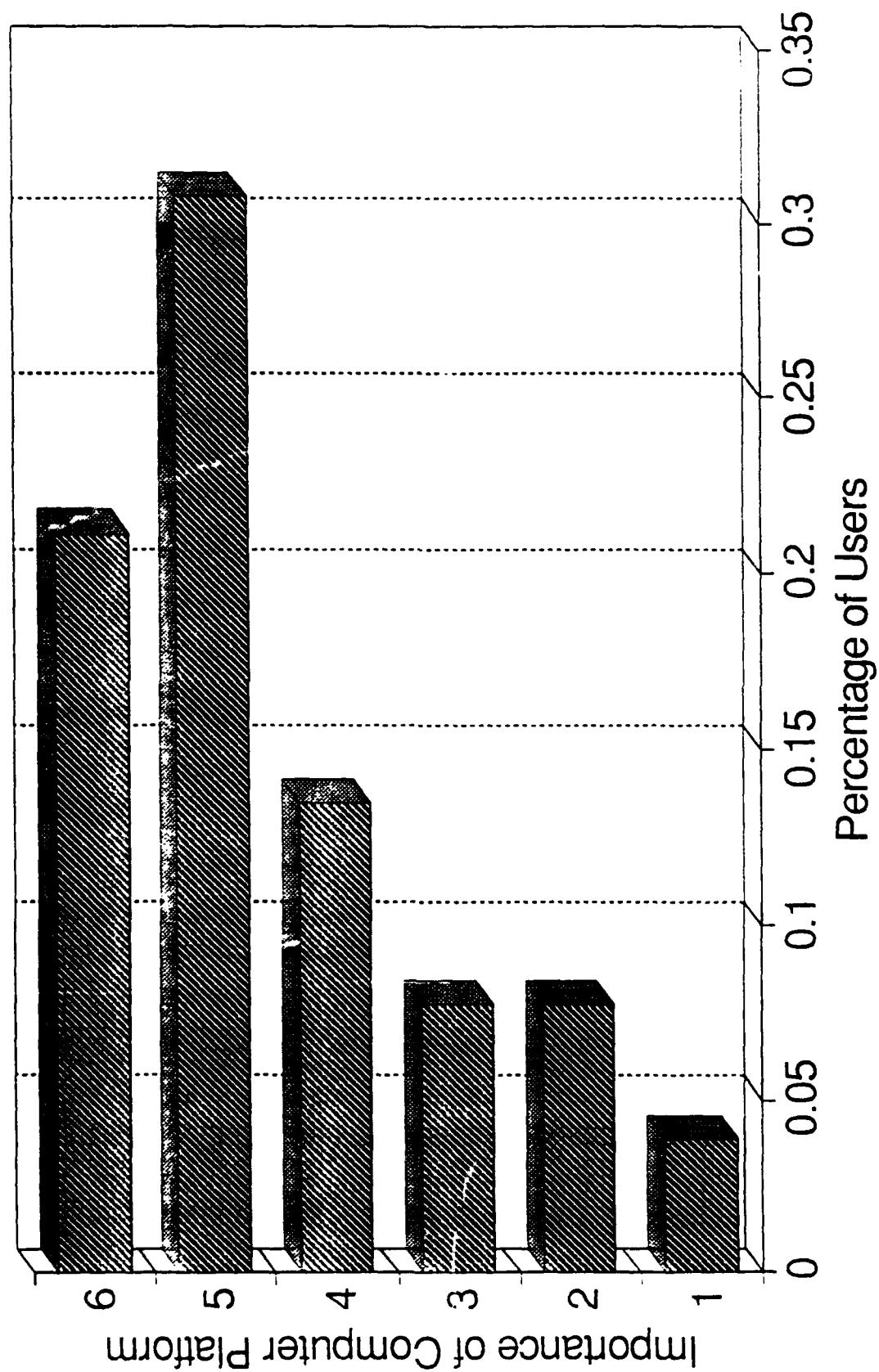


FIGURE 7

# Choosing a CAE Tool

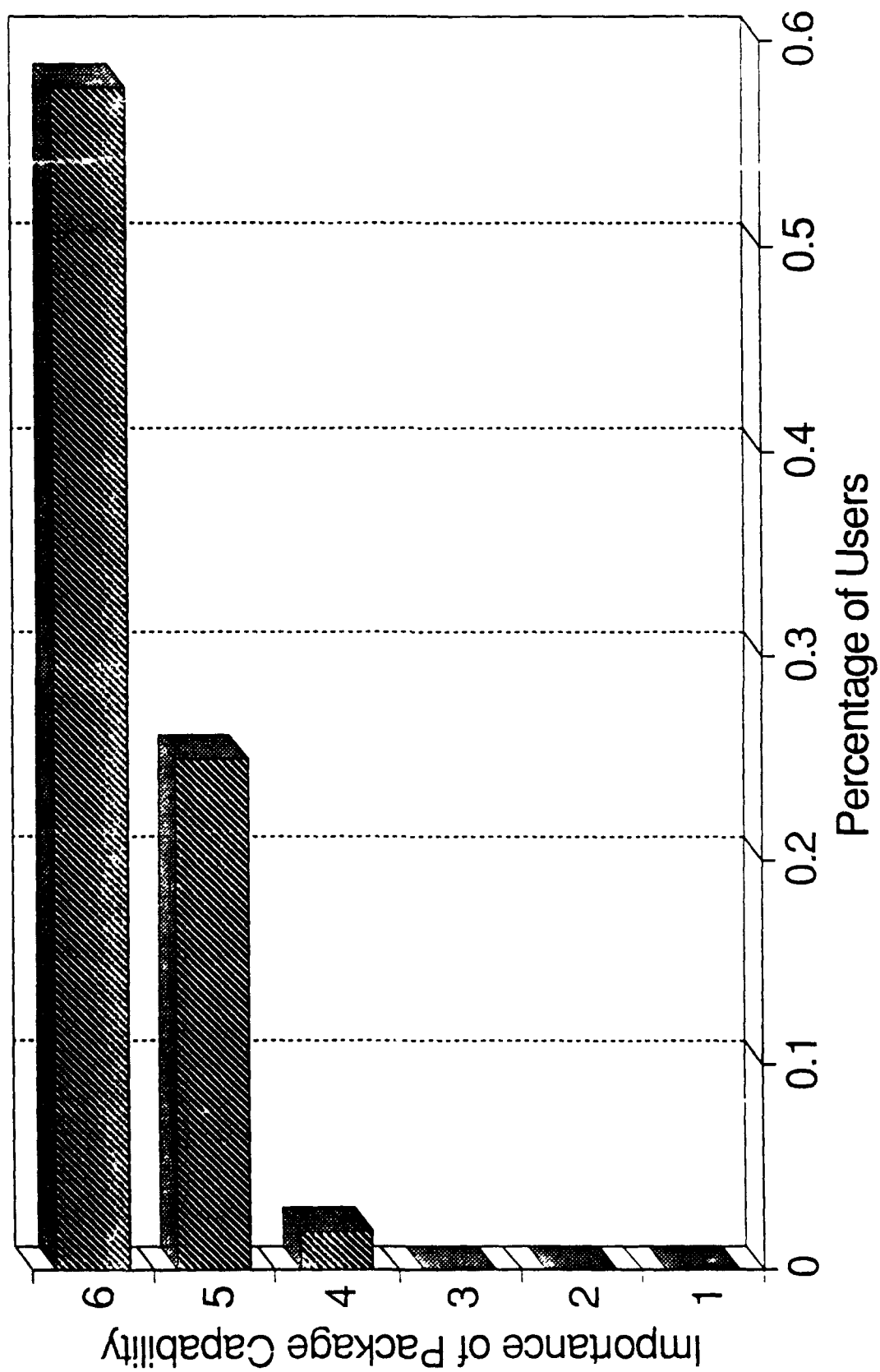


FIGURE 8

# Choosing a CAE Tool

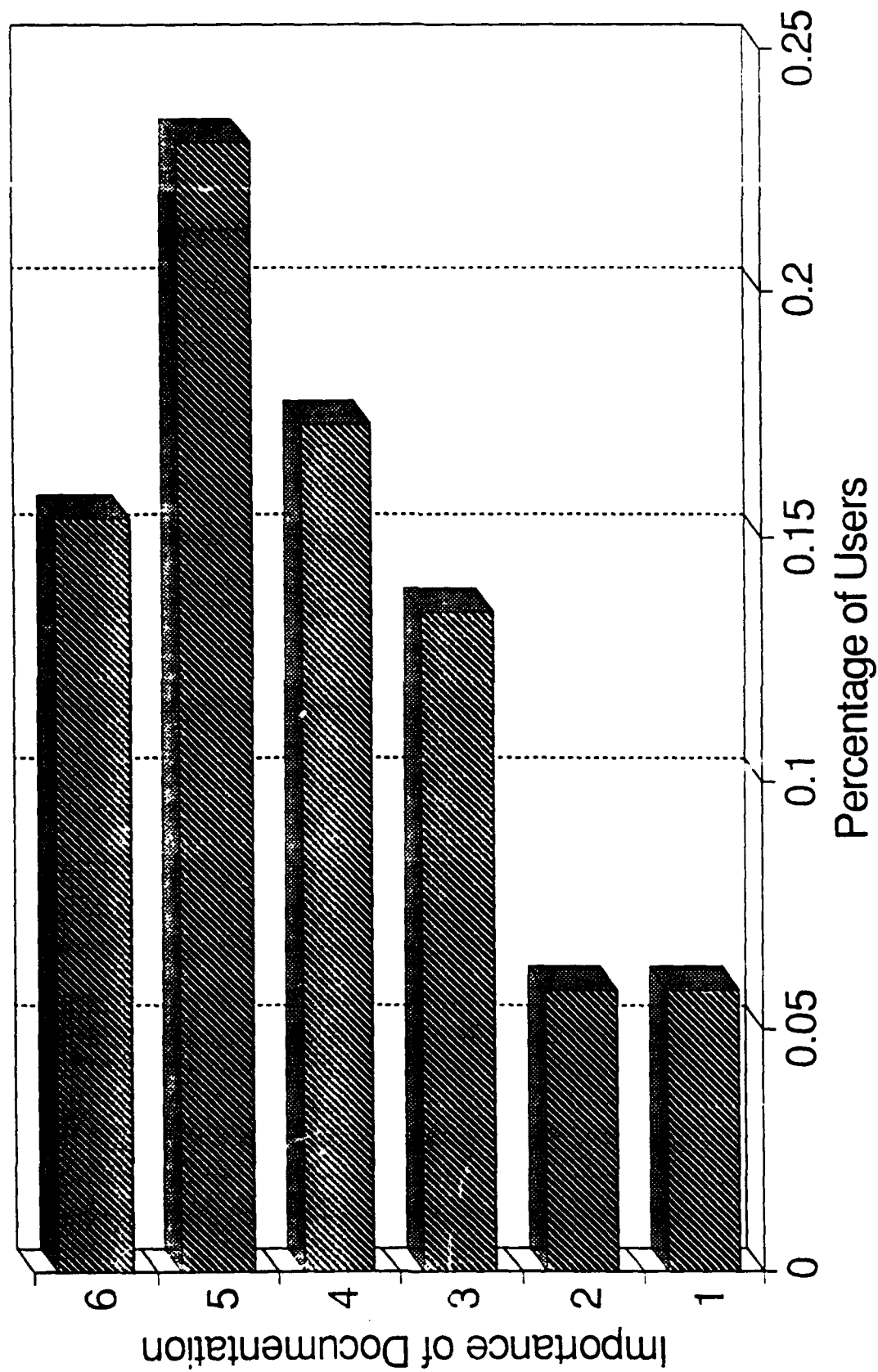


FIGURE 9



## Commercial CAE Package Usage

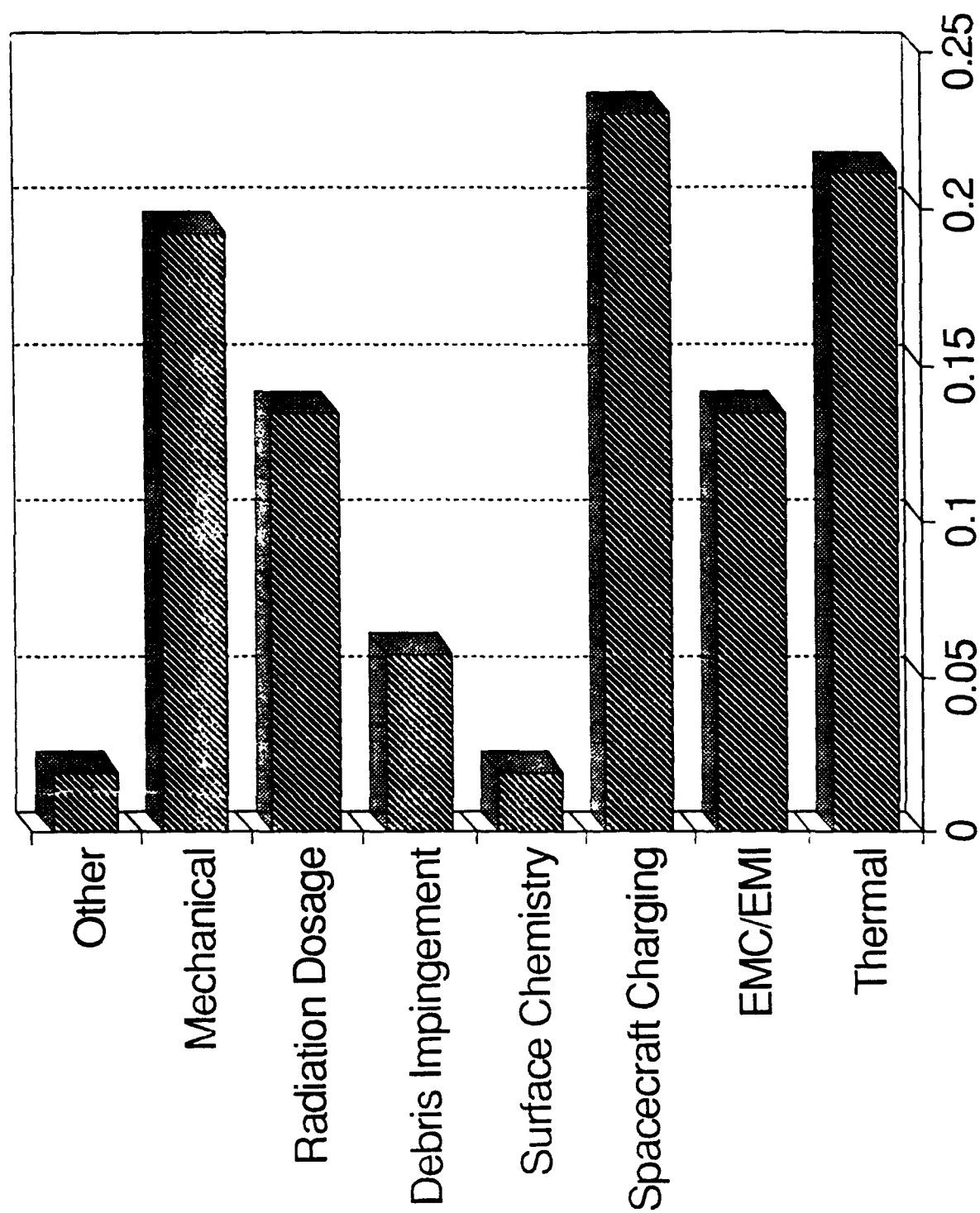


FIGURE 10

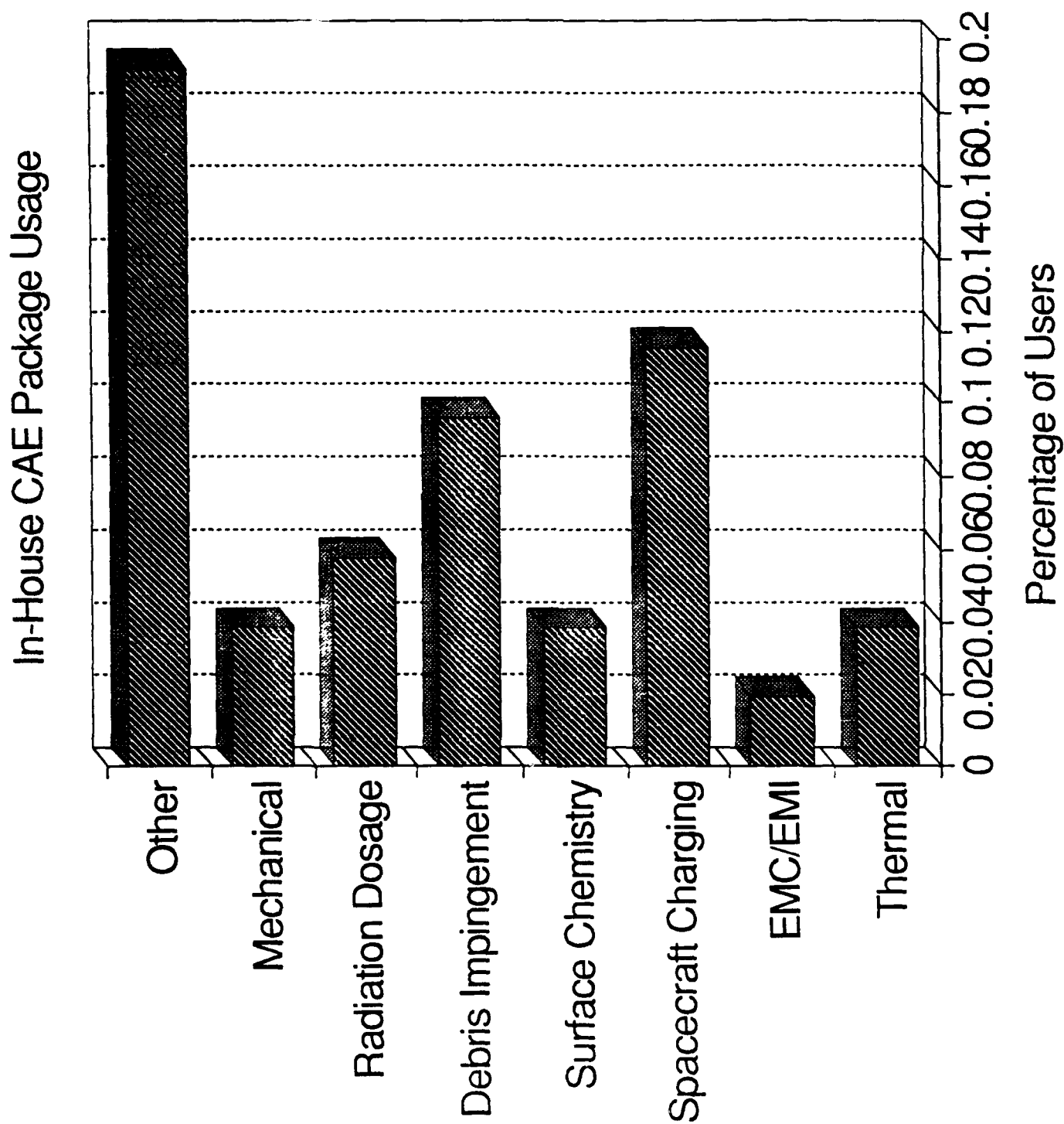


FIGURE 11

# Models Used with Commercial Package

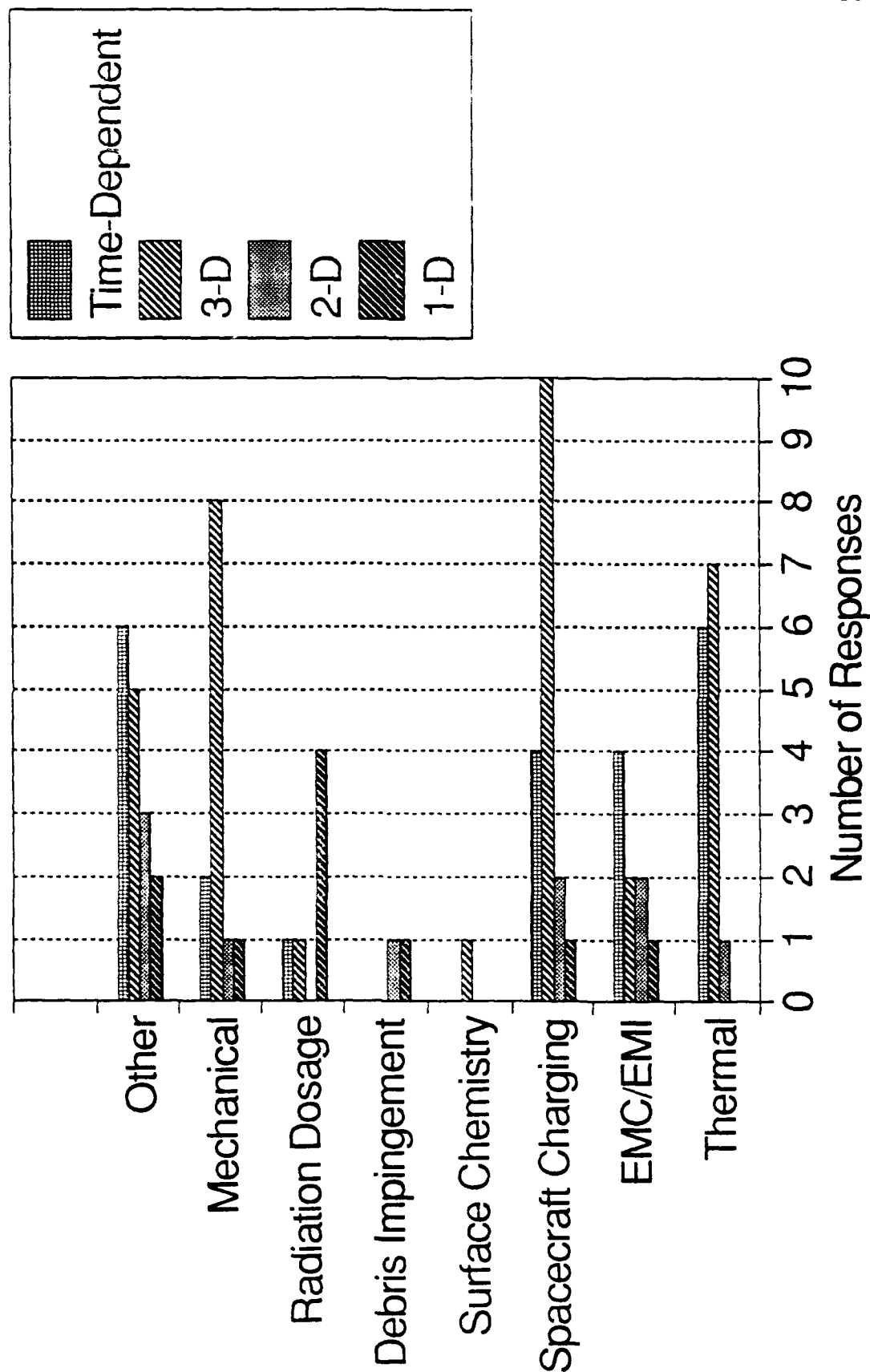


FIGURE 12

# Accept Standard CAD/CAM Input?

(Commercial Packages)

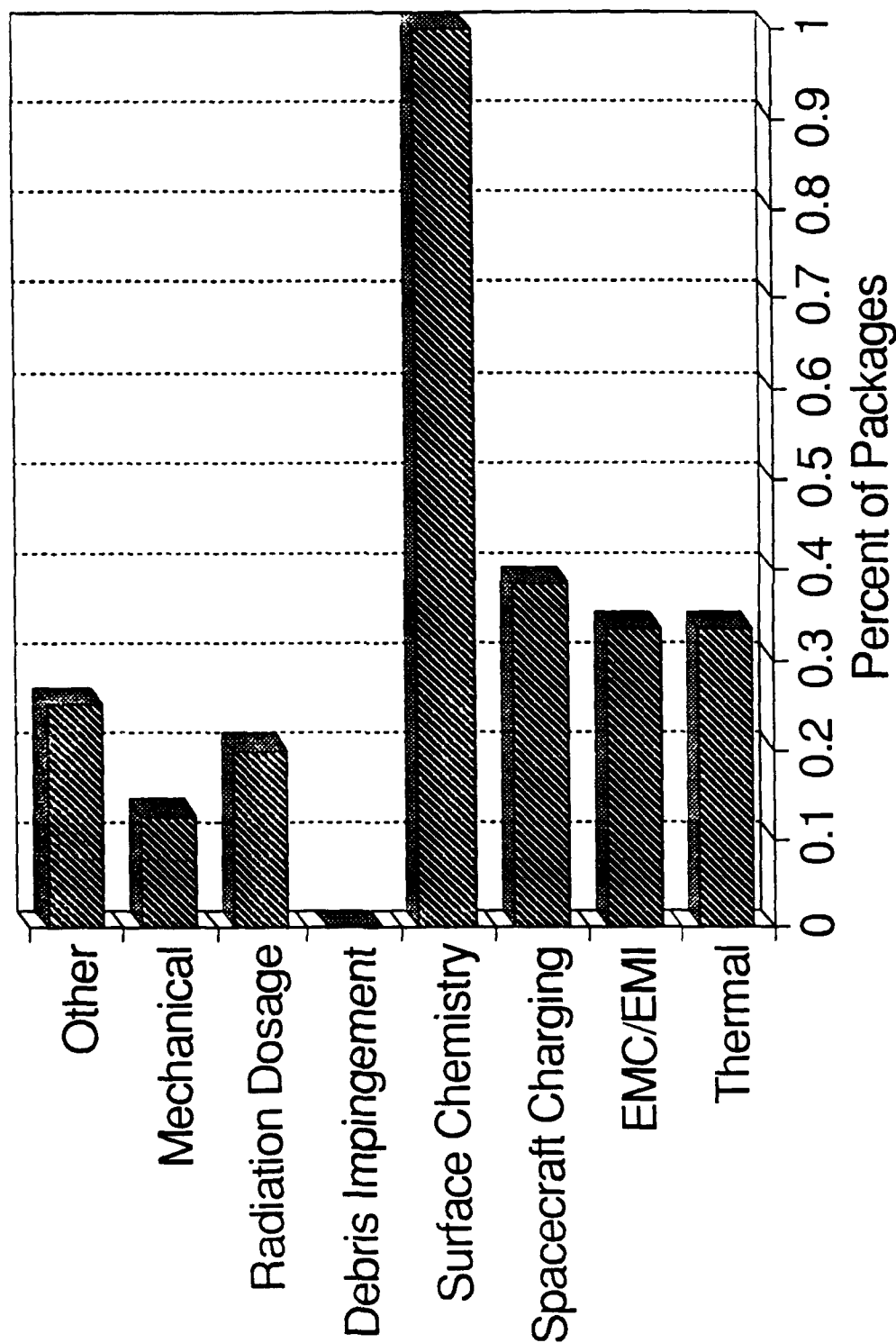


FIGURE 13

# Graphic Output? (Commercial Packages)

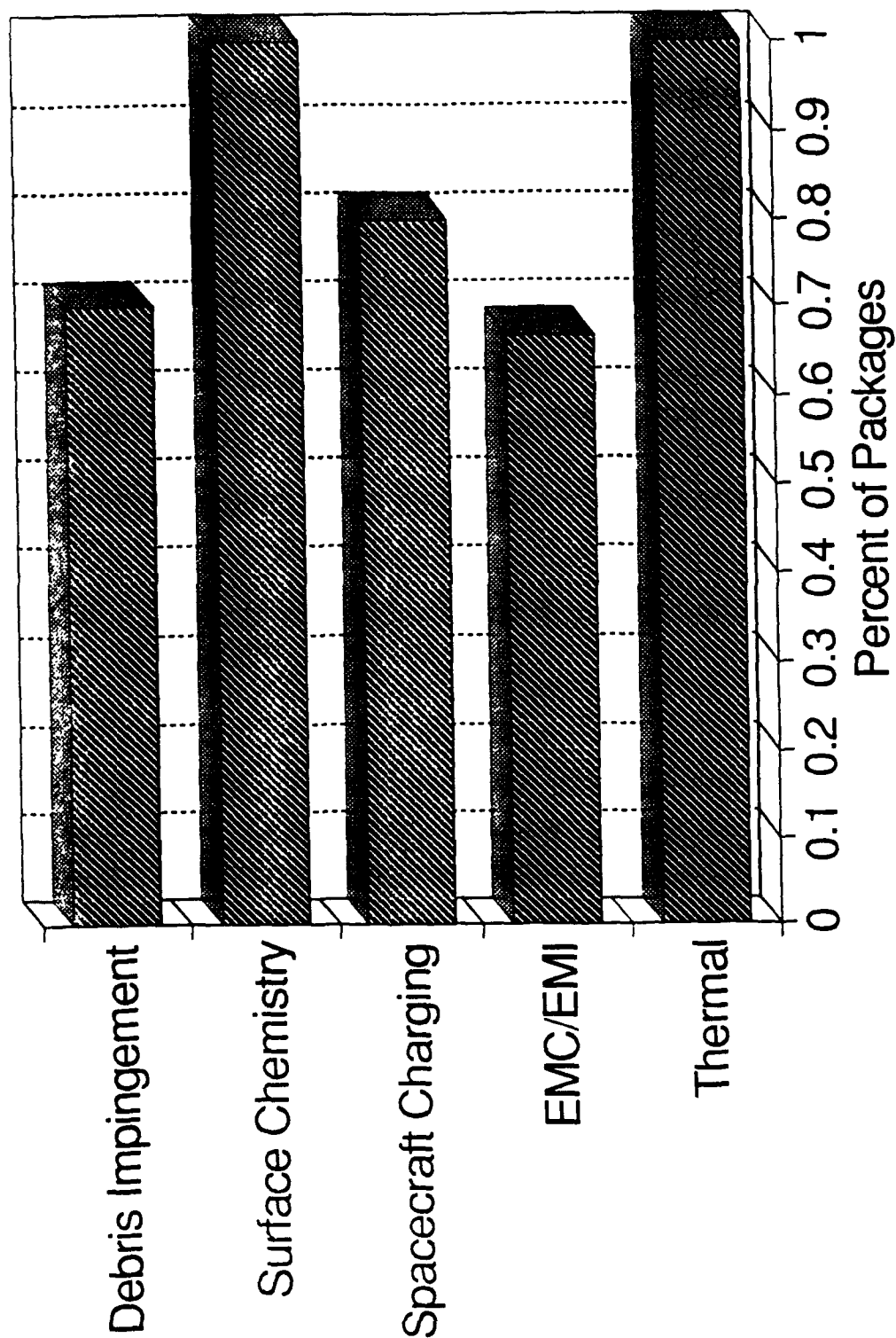


FIGURE 14

# Input to Post-Processing Packages? (Commercial Packages)

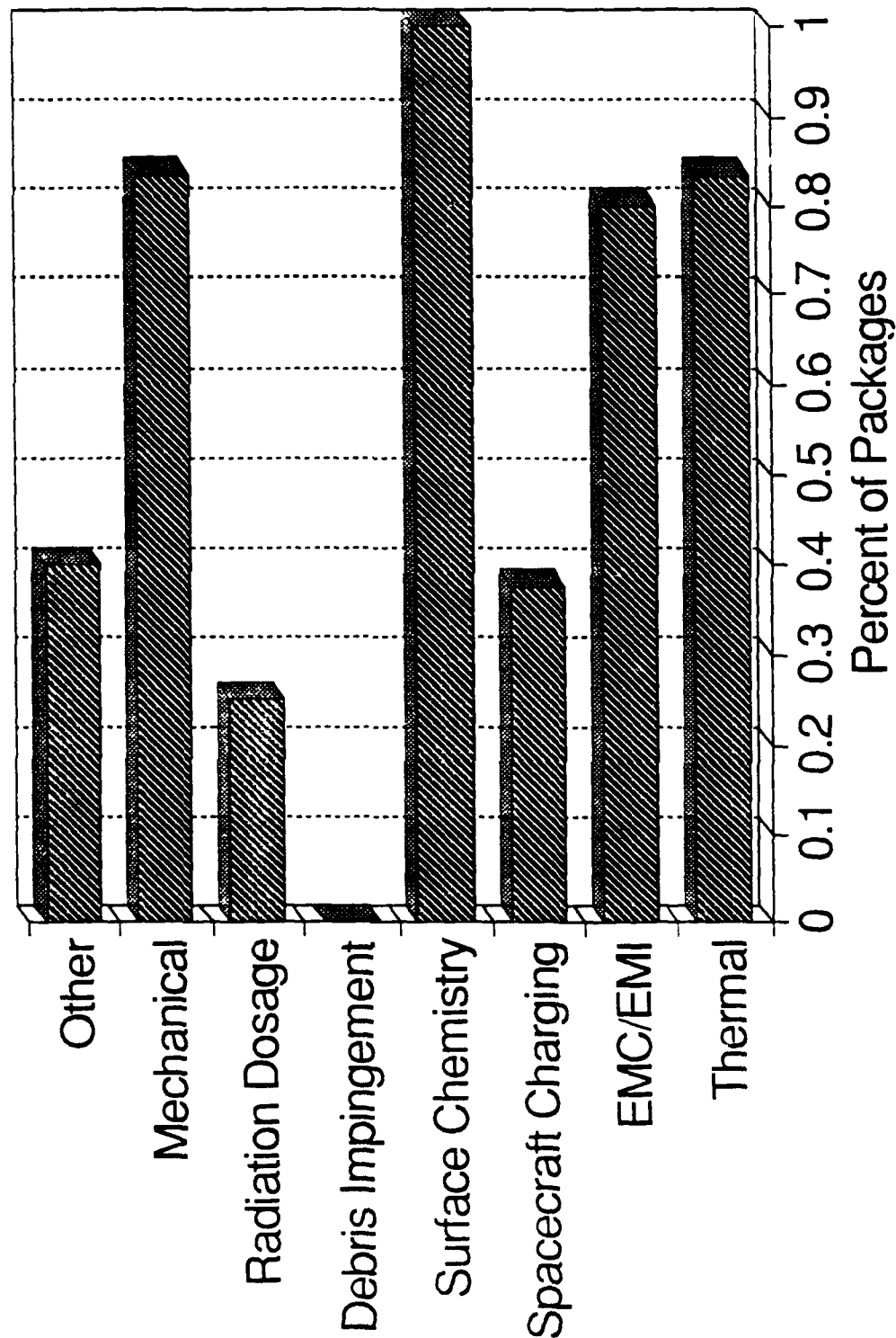


FIGURE 15

# How Extensively Used (Commercial Packages)

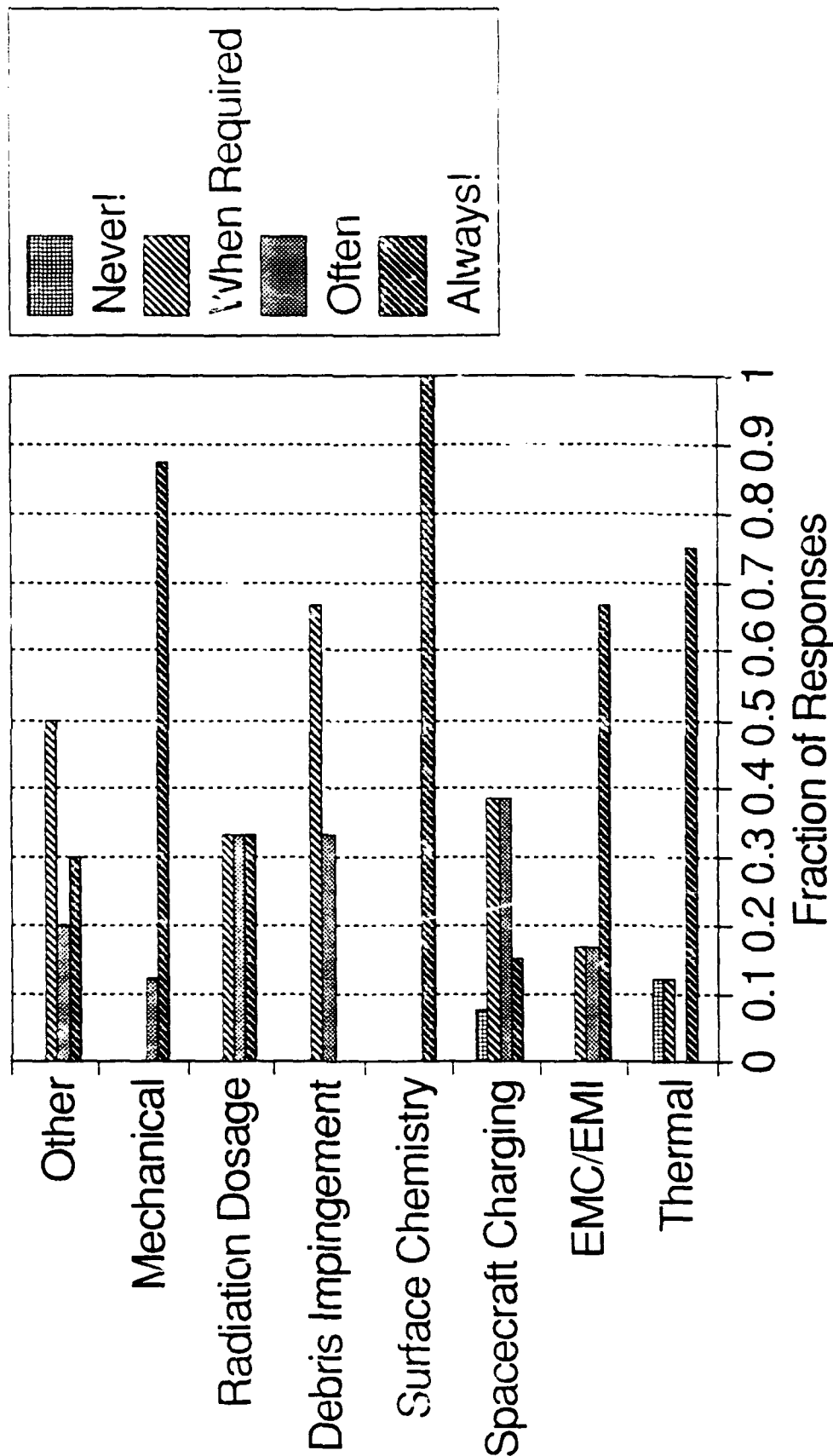


FIGURE 16

# Where in Design Process Is it Used?

(Commercial Packages)

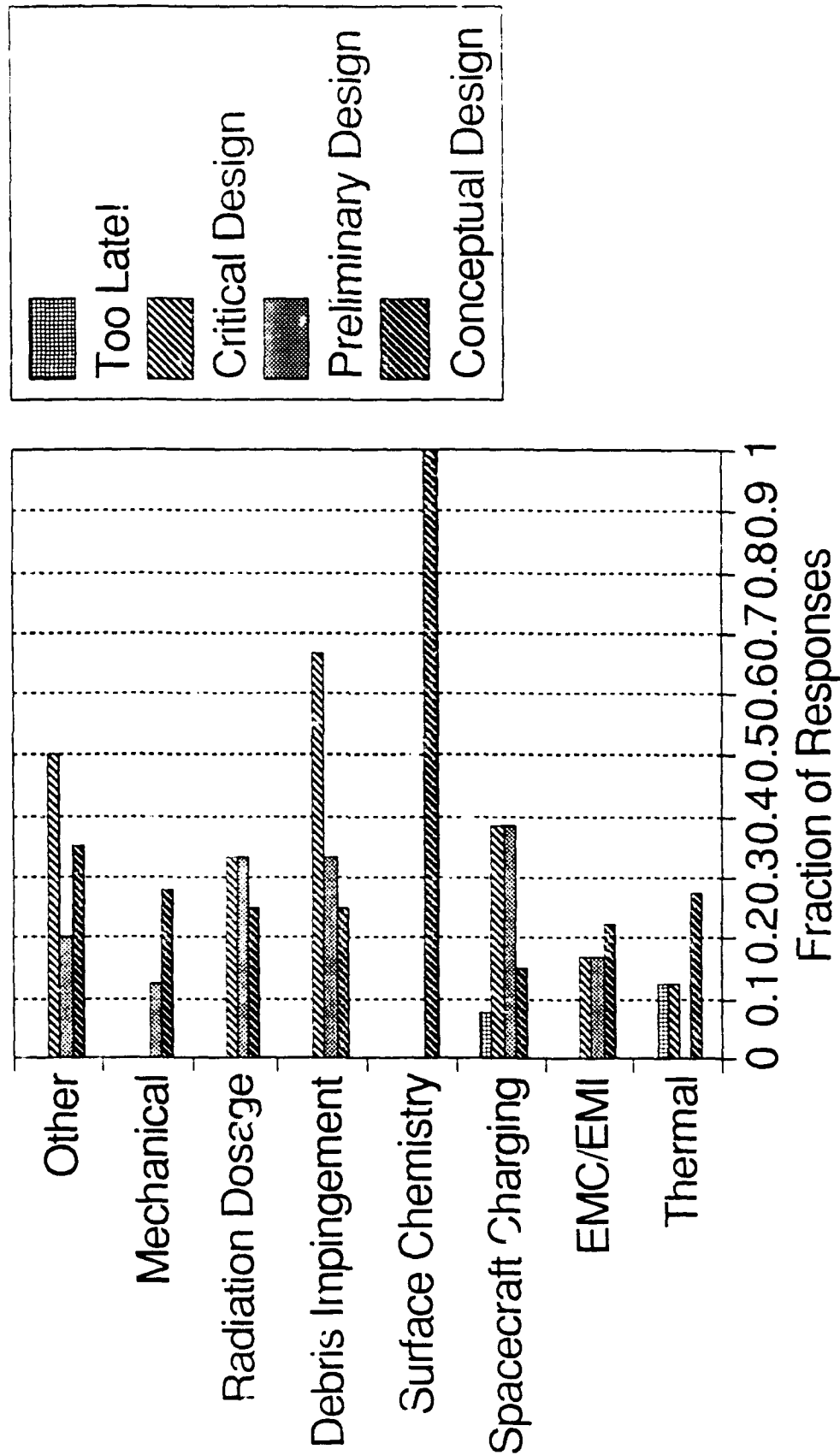


FIGURE 17



# Training Required (Commercial Packages)

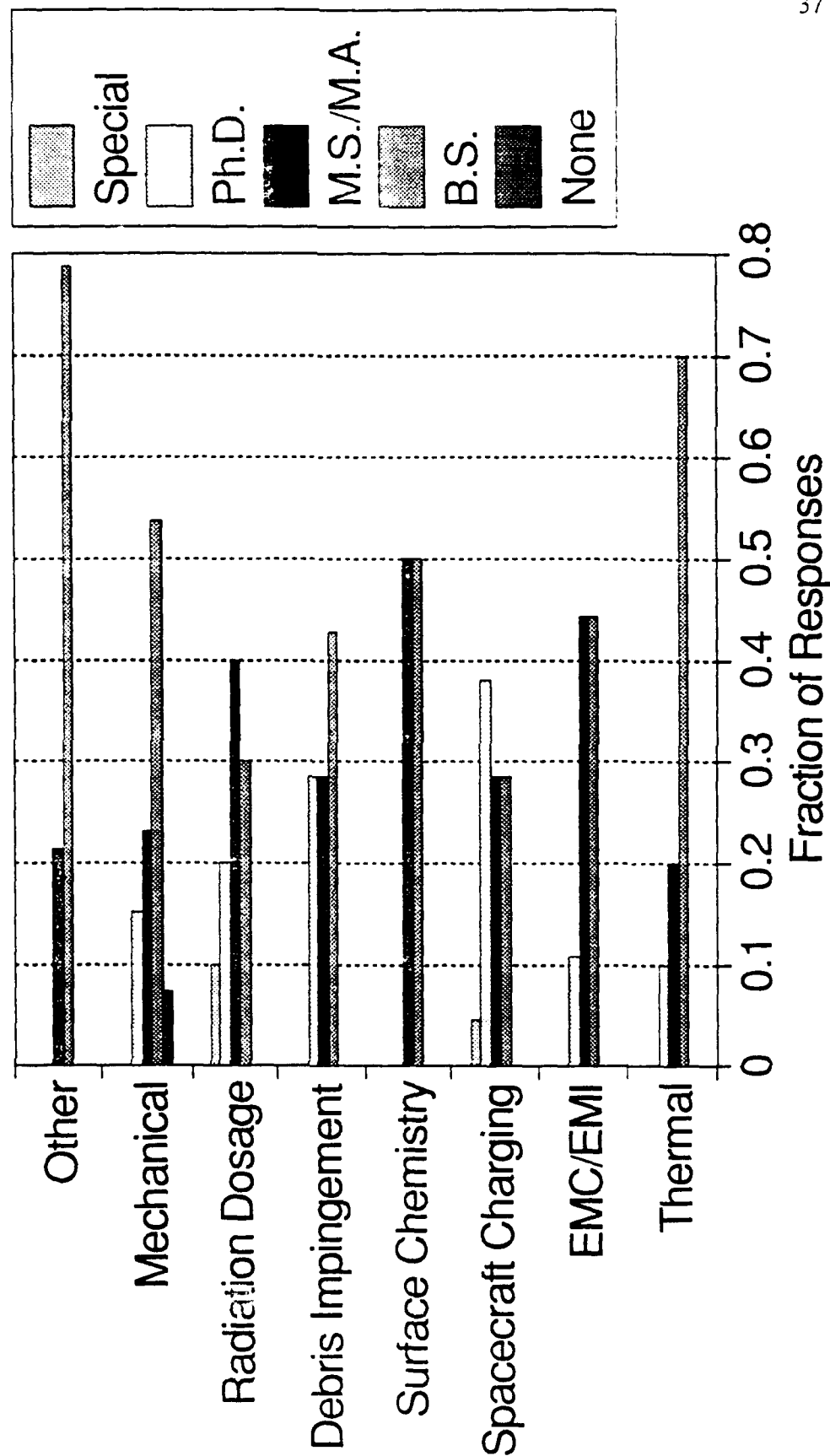


FIGURE 18

# Models Used with In-House Package

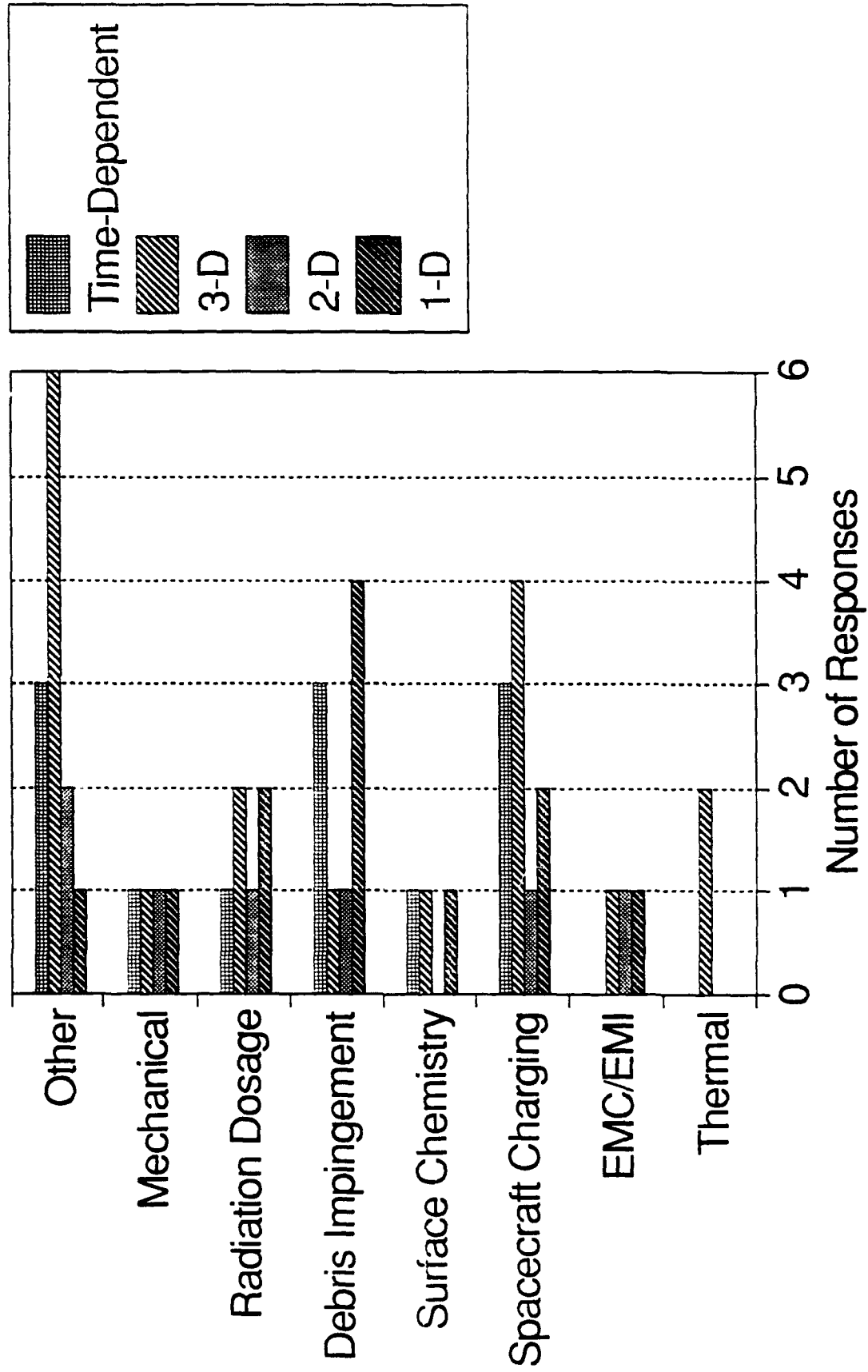


FIGURE 19

# Accept Standard CAD/CAM Input?

(In-House Packages)

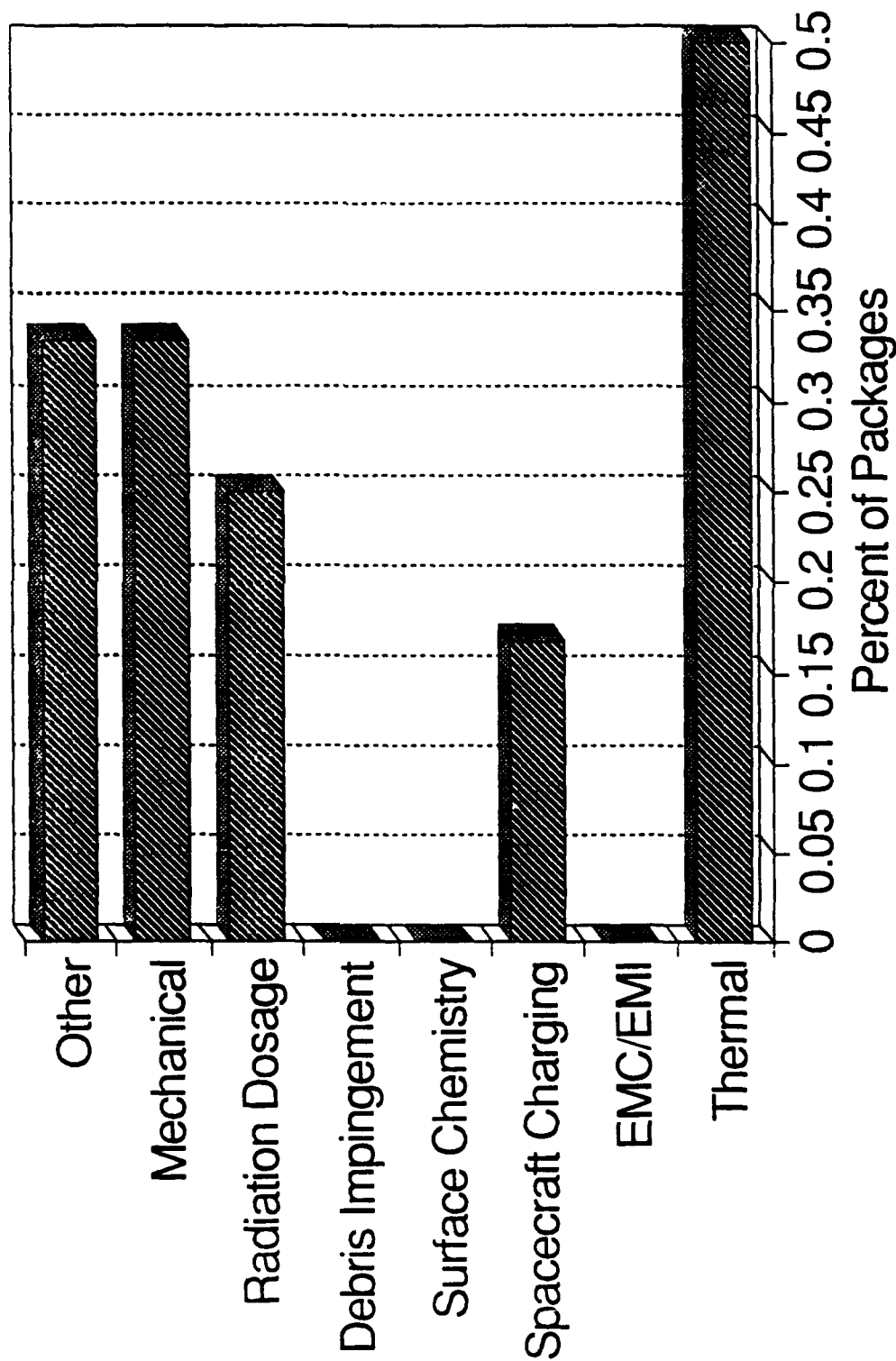


FIGURE 20

# Graphic Output (In-House Packages)

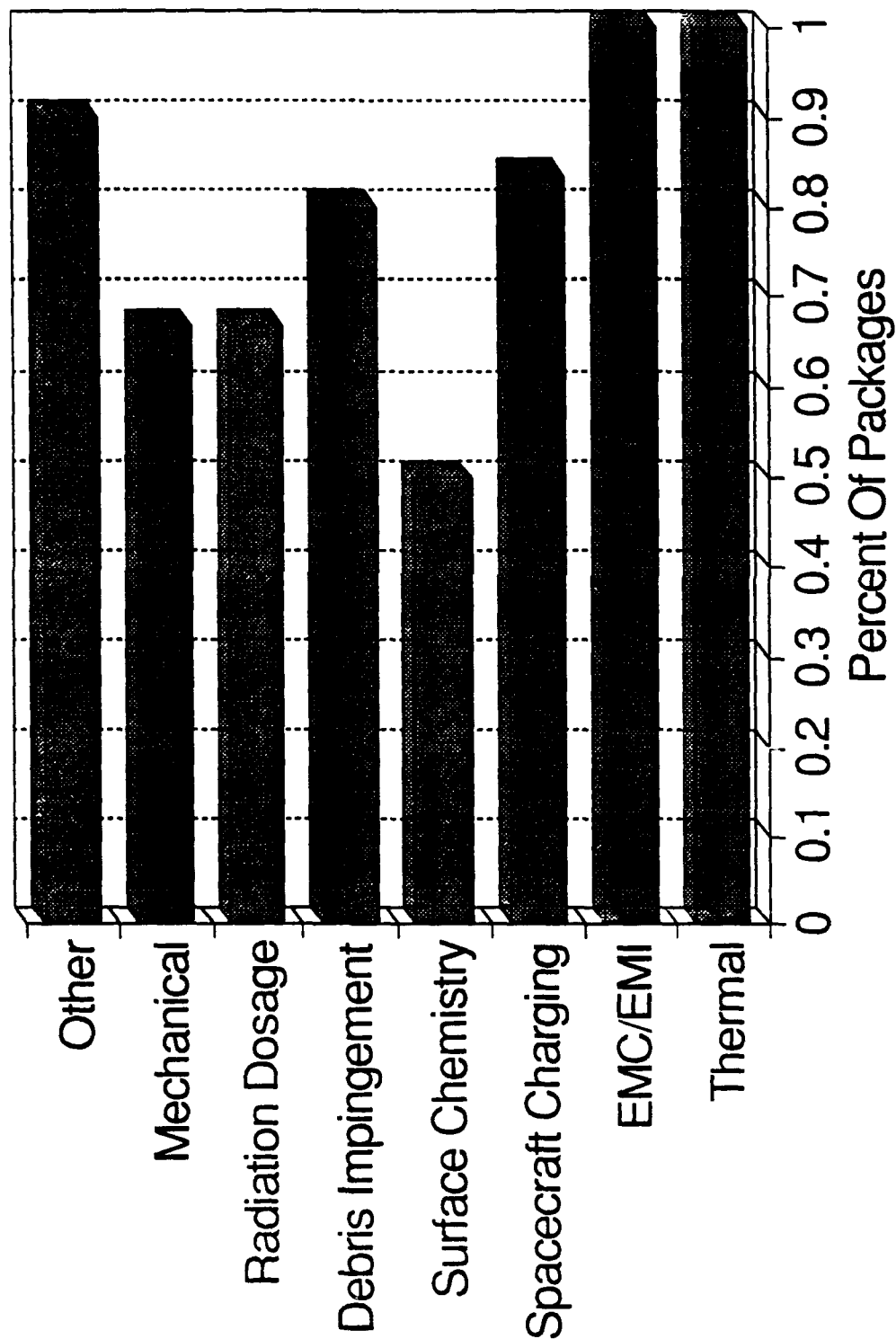


FIGURE 21

# Input to Post-Processing Packages? (In-House Packages)

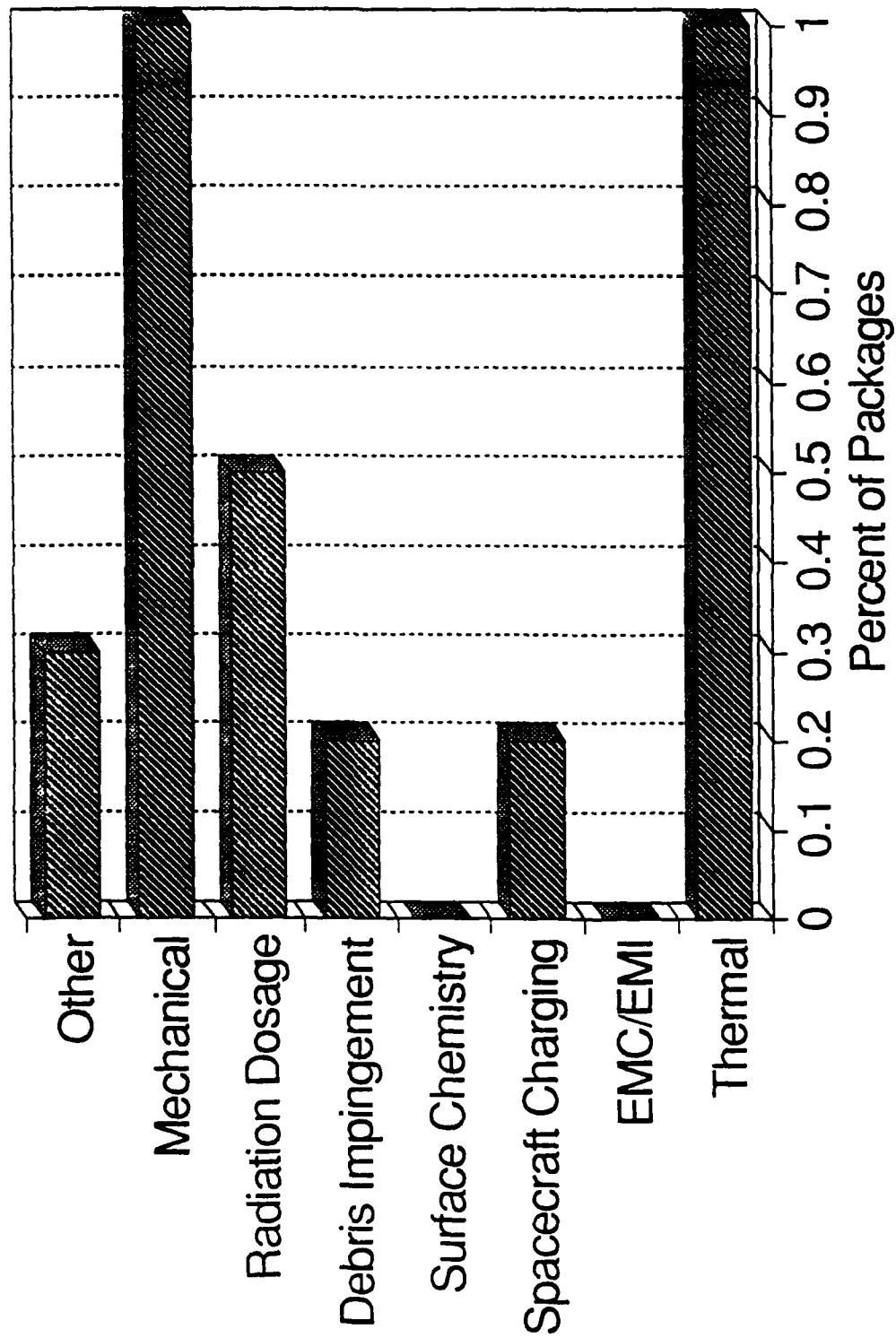


FIGURE 22

# How Extensively Used (In-House Packages)

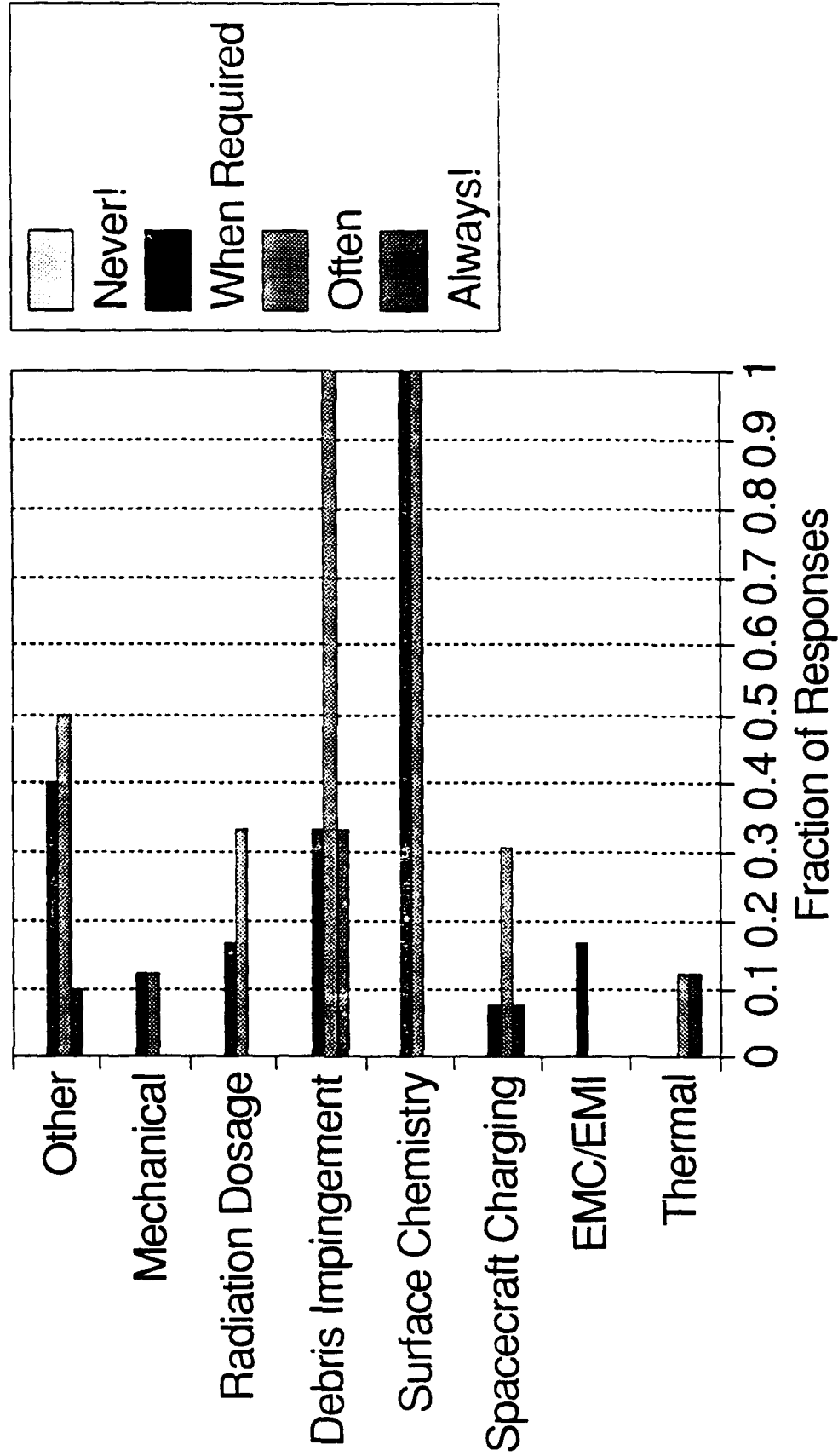


FIGURE 23

# Where in Design Process Is It Used?

## (In-House Packages)

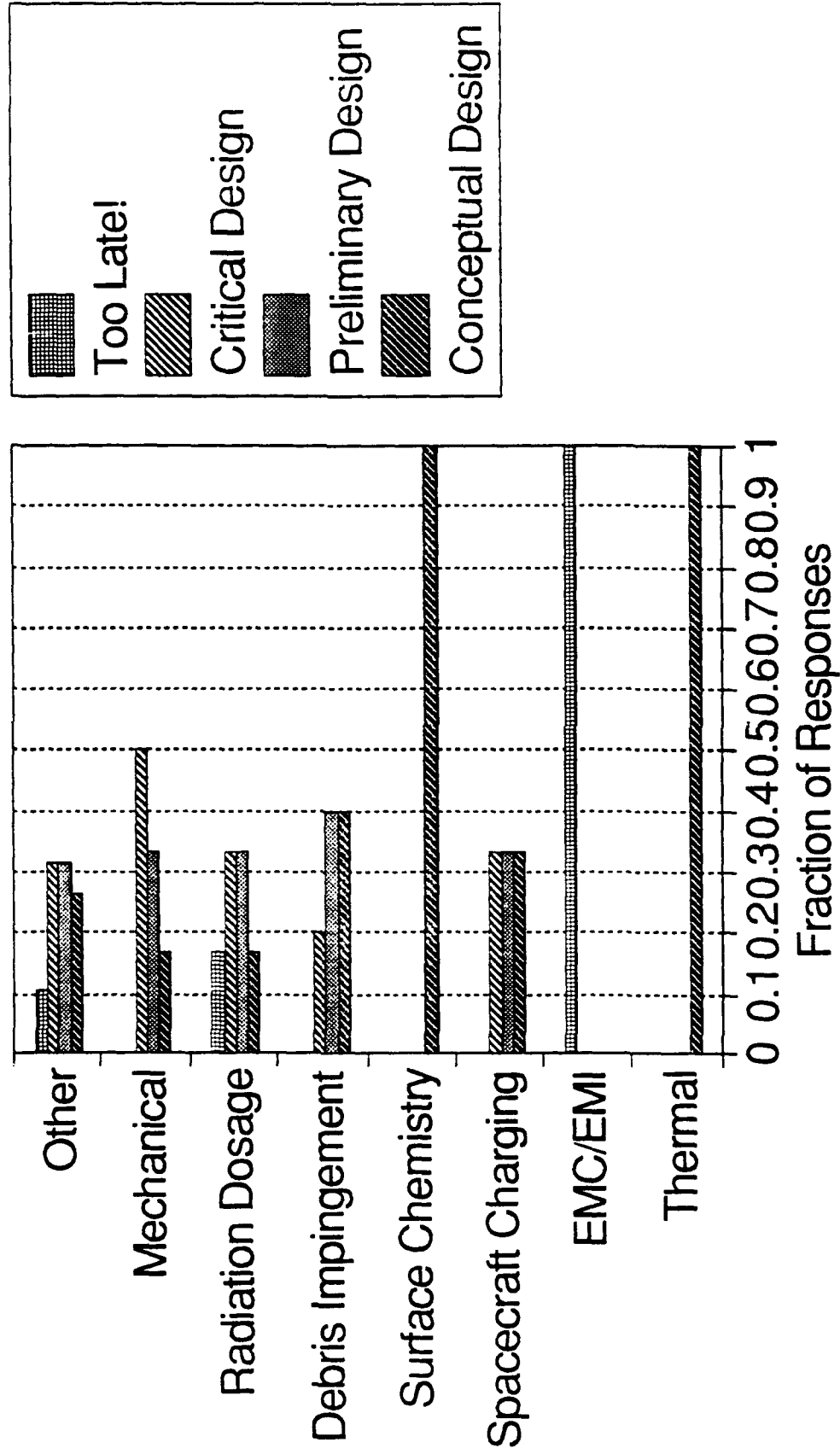


FIGURE 24

# Training Required (In-House Packages)

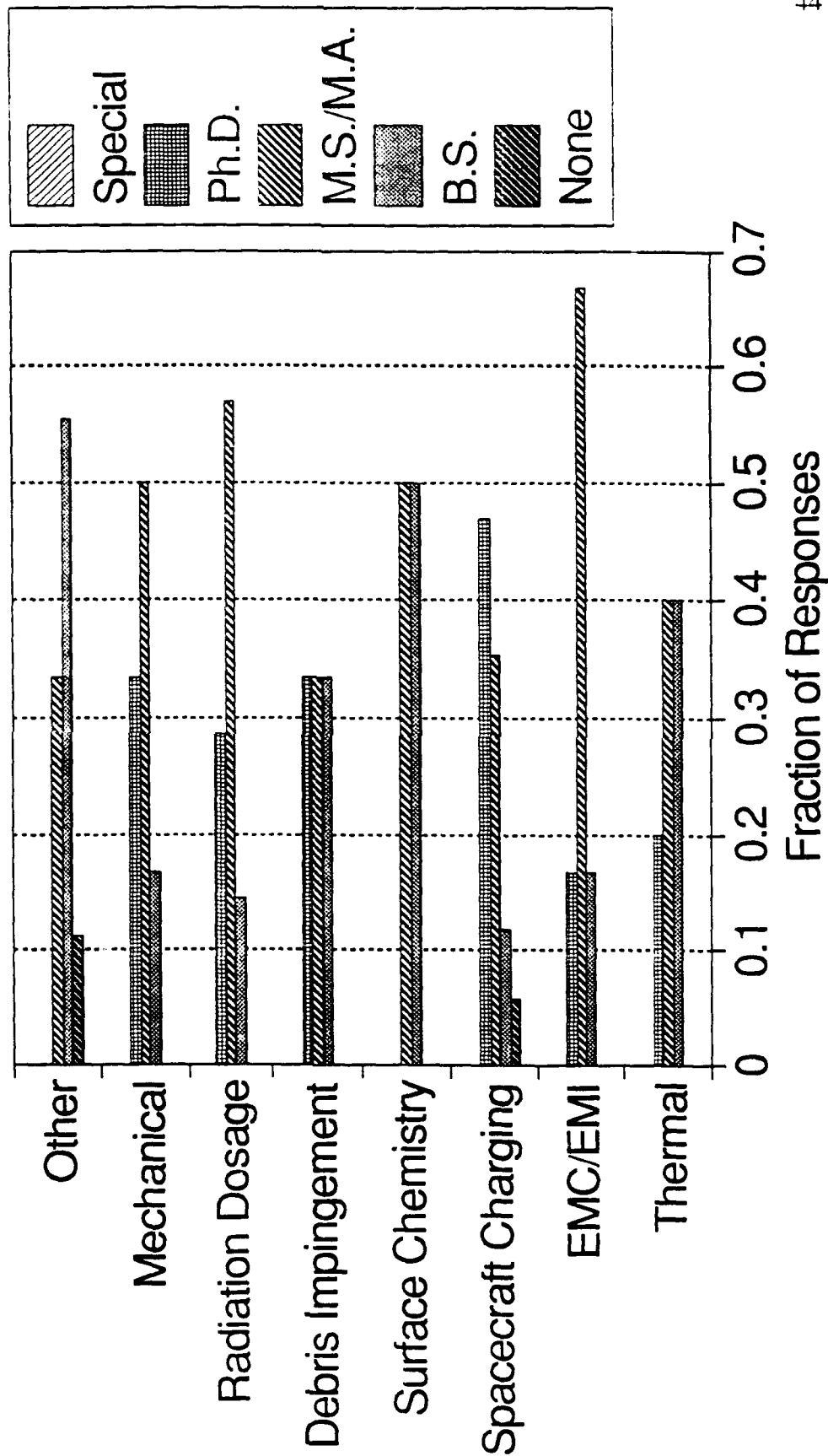


FIGURE 25



# What CAD/CAM Software is Available?

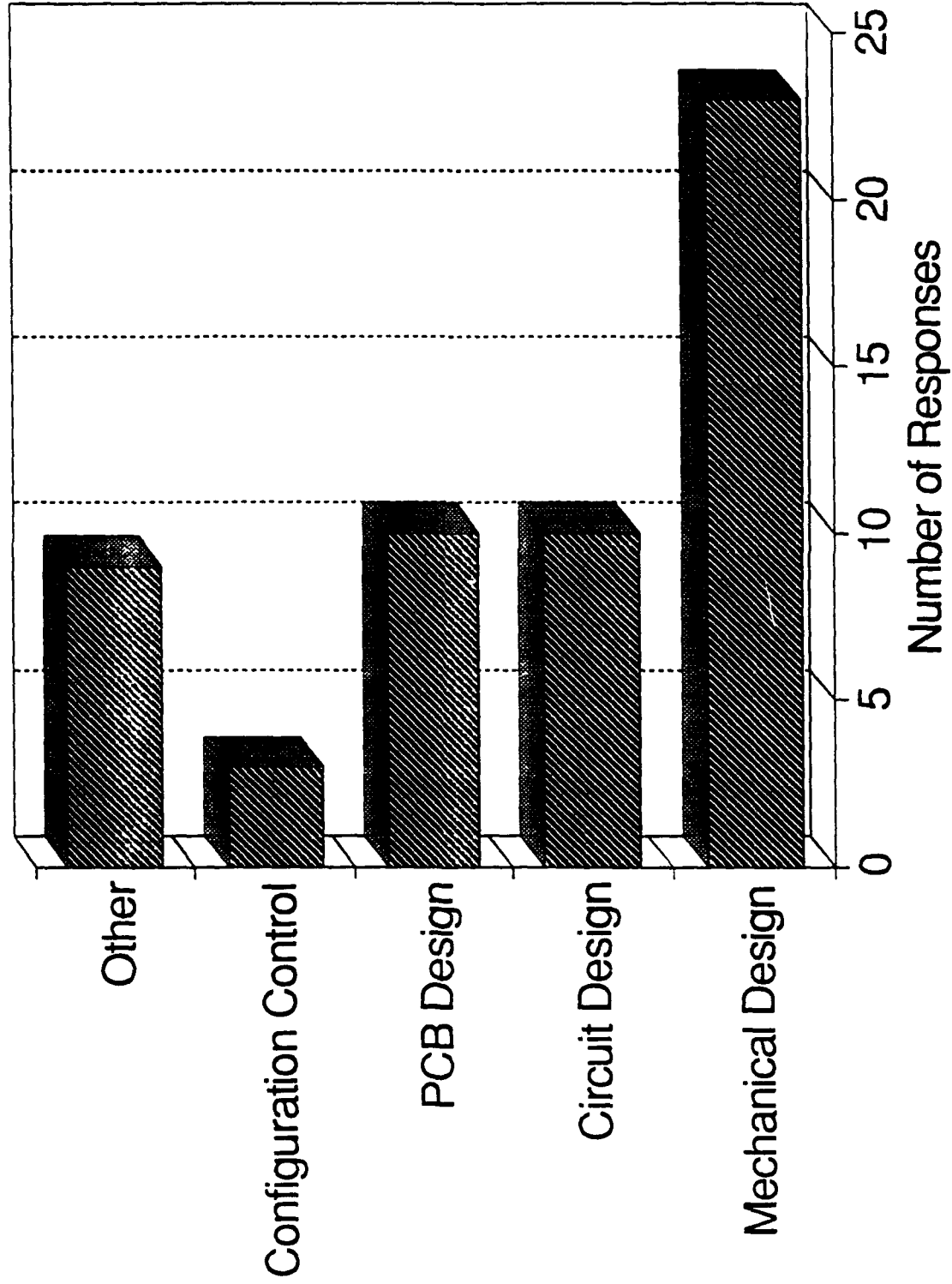


FIGURE 26

# Can CAD/CAM Exchange Data with Other Packages?

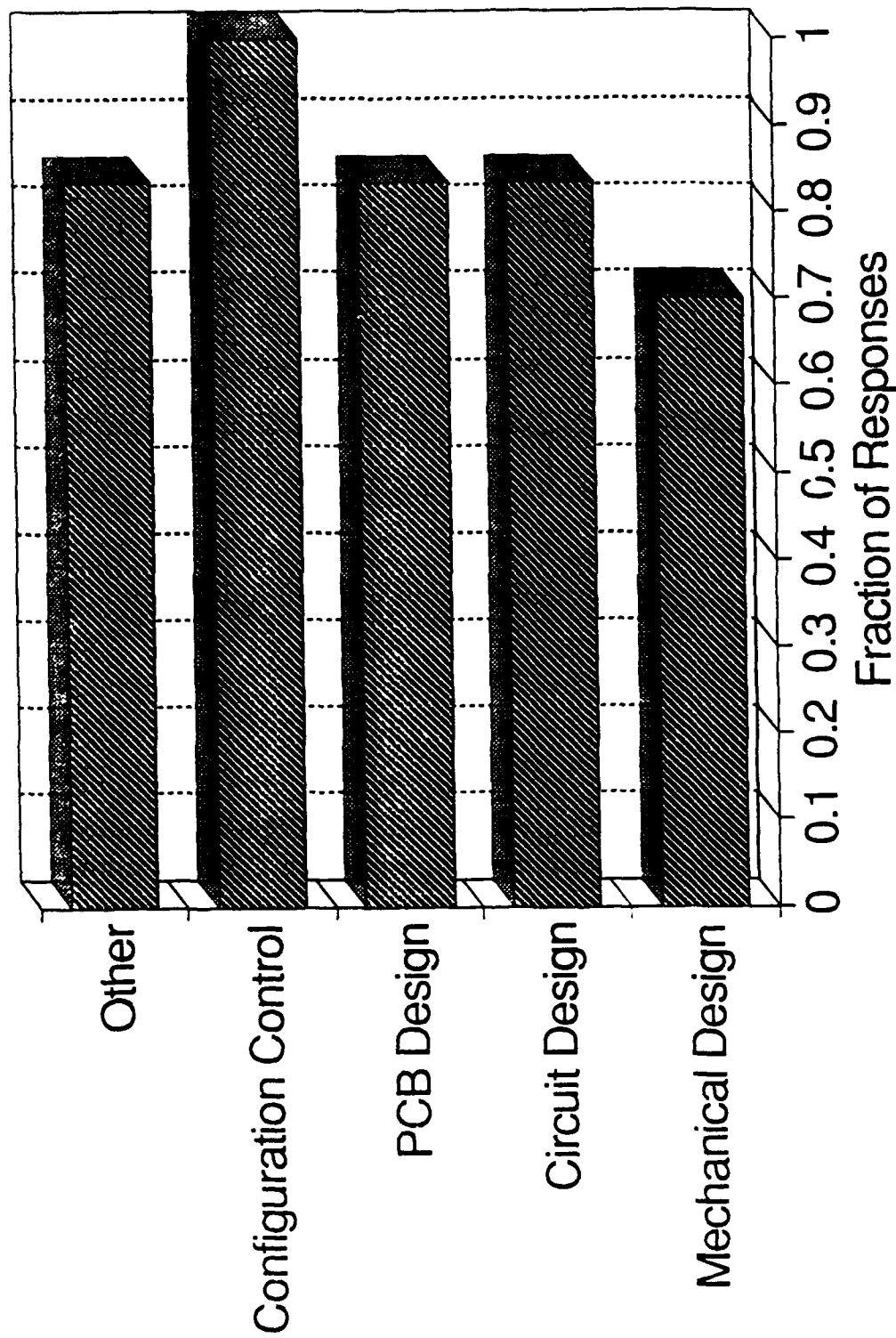


FIGURE 27

# Standard CAD/CAM Output Formats

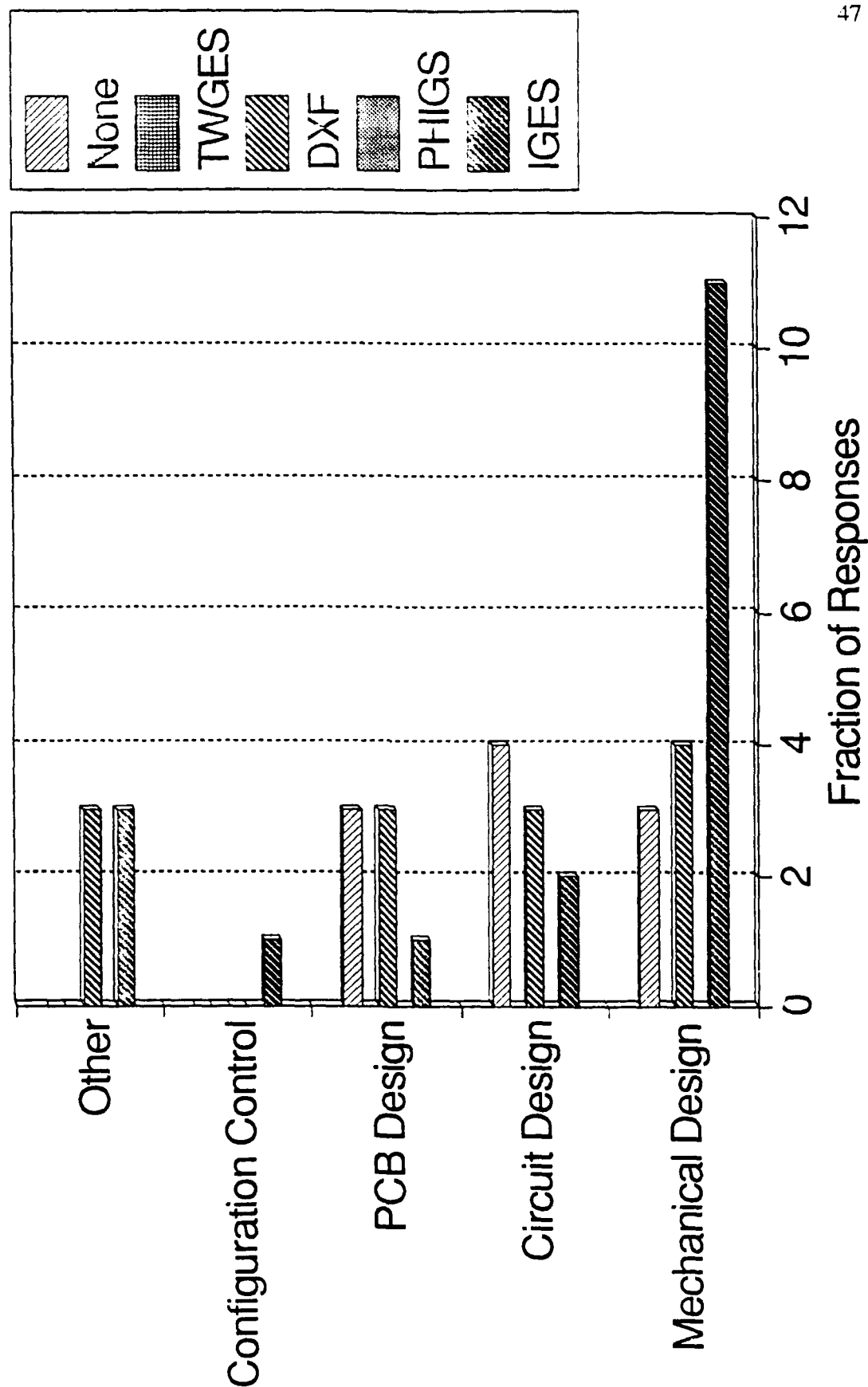


FIGURE 28

# Computing Environment

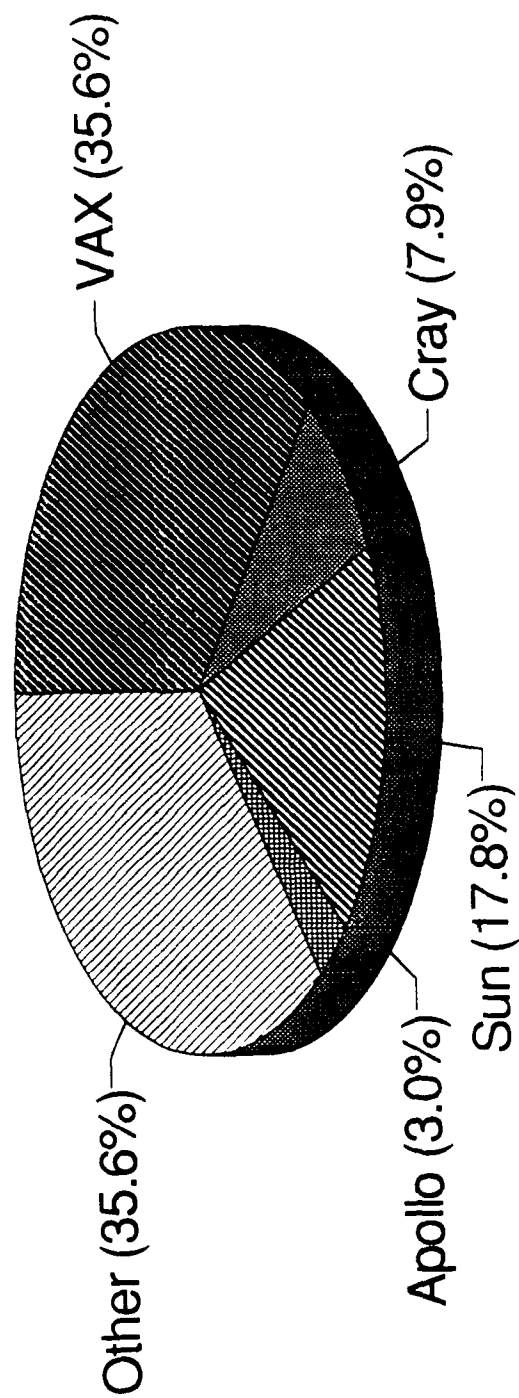


FIGURE 29

# Network Access

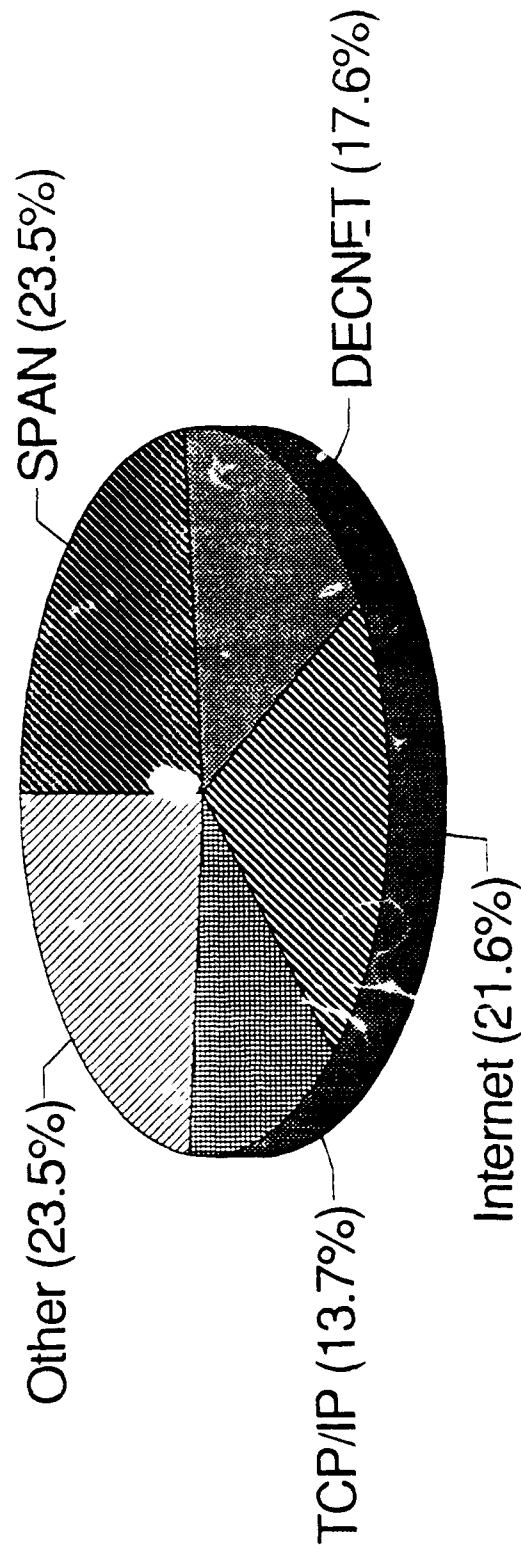


FIGURE 30

# Operating System

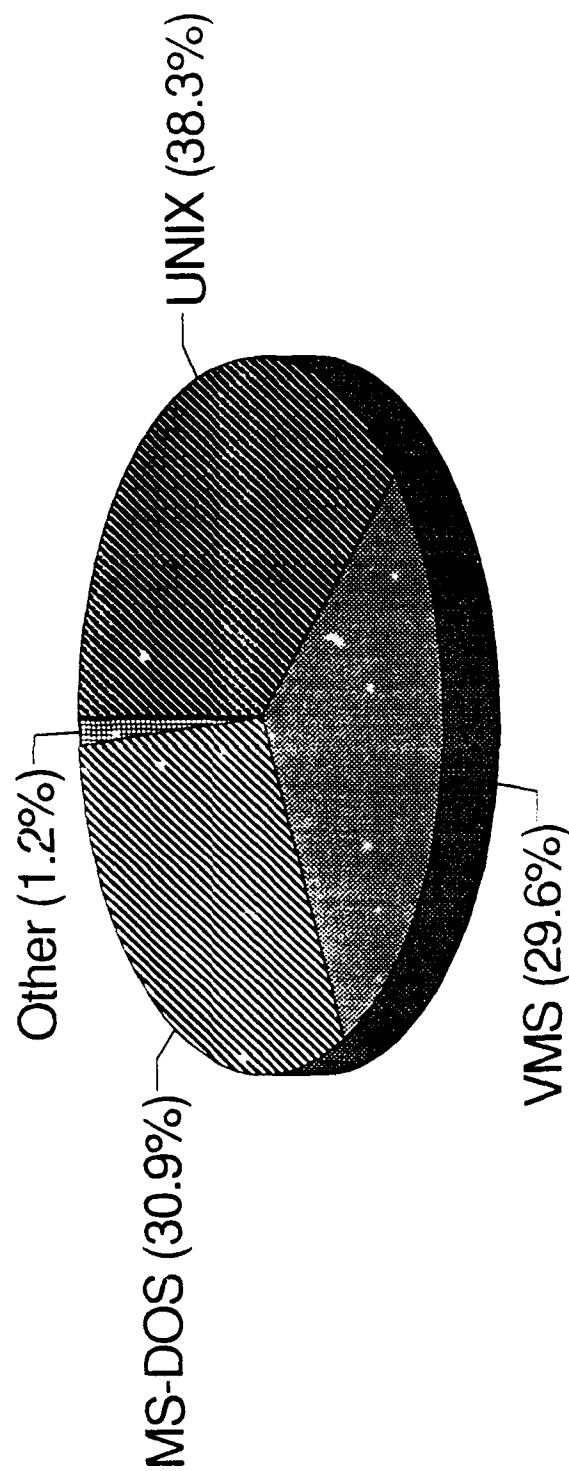


FIGURE 31

# Graphics Capability

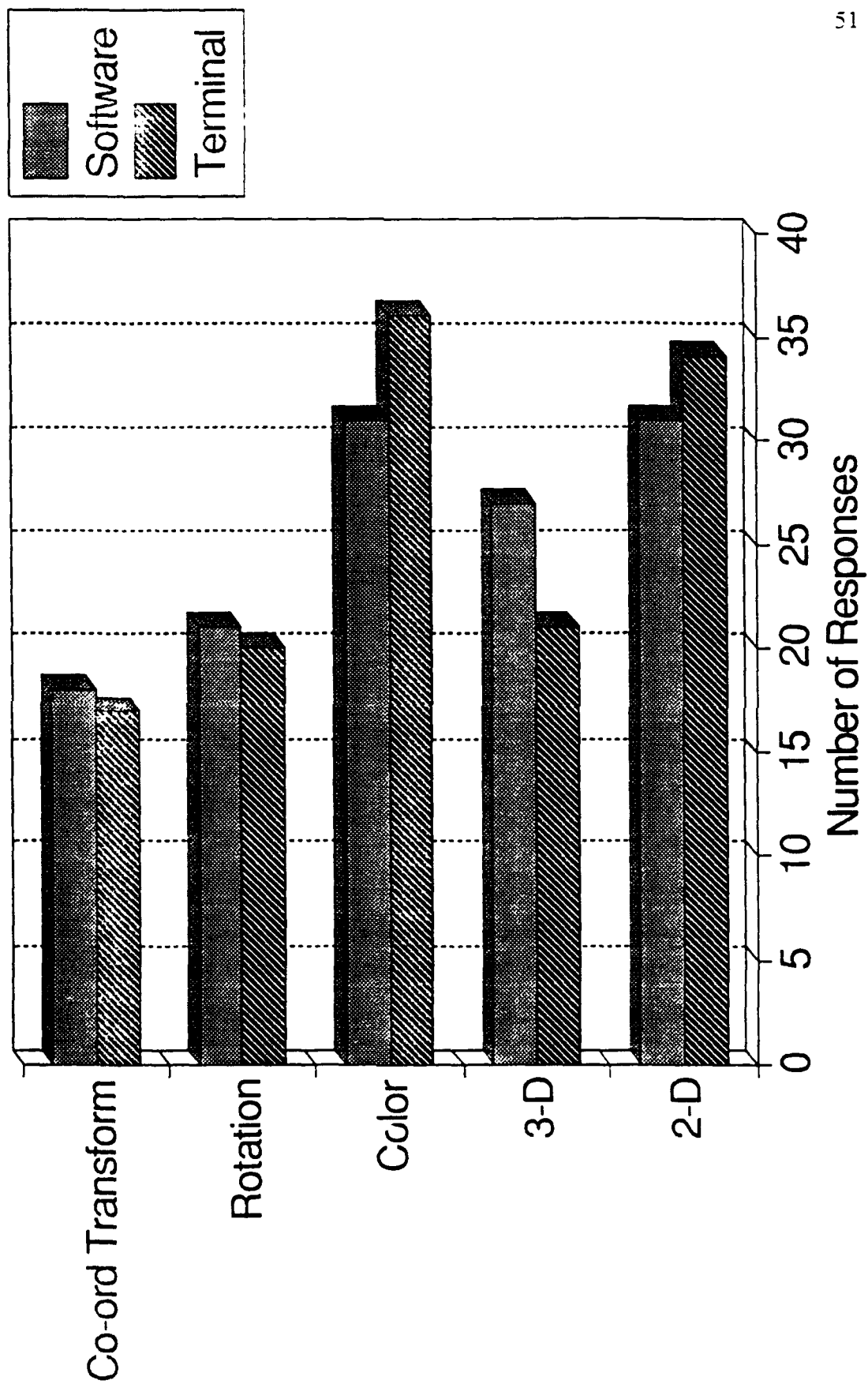


FIGURE 32

## Integrated CAD/CAM with Environmental Analysis Tool --

How Important Would It Be?

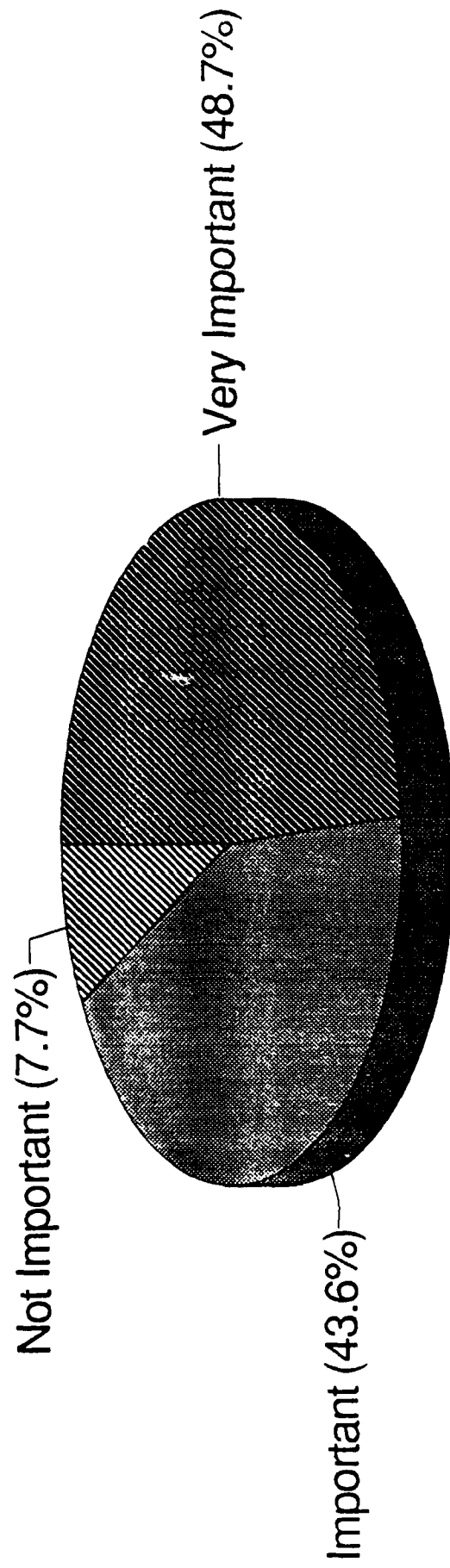


FIGURE 33



# 386i or Workstation-Based Spreadsheet type Program ---

How Important Would It Be?

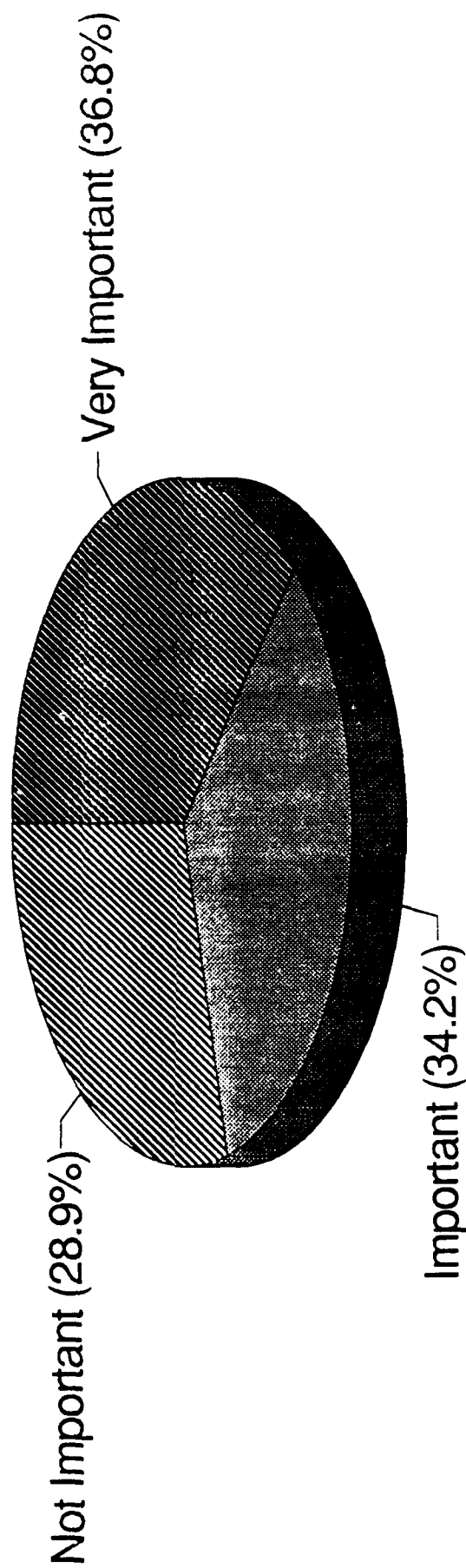


FIGURE 34

## A User-Friendly Screen-Oriented Front End Tailored to a Specific Analysis --

How Important Would It Be?

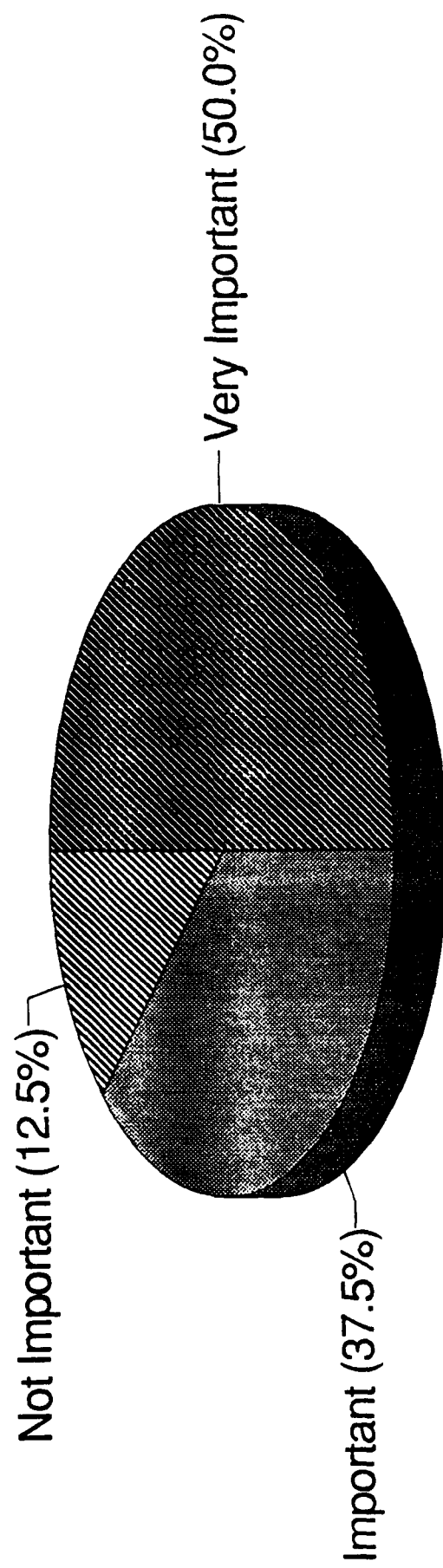


FIGURE 35

Do you think it is important that an integrated CAE tool in which all the analyses can be performed should be available?

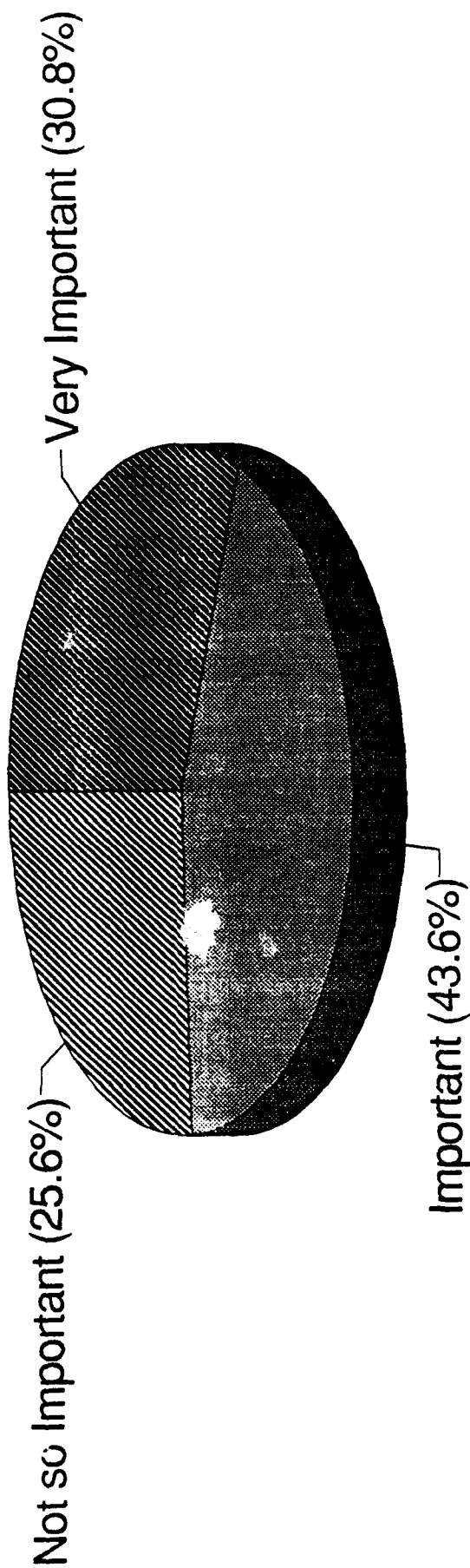


FIGURE 36

What CAE aids would you like to see developed?

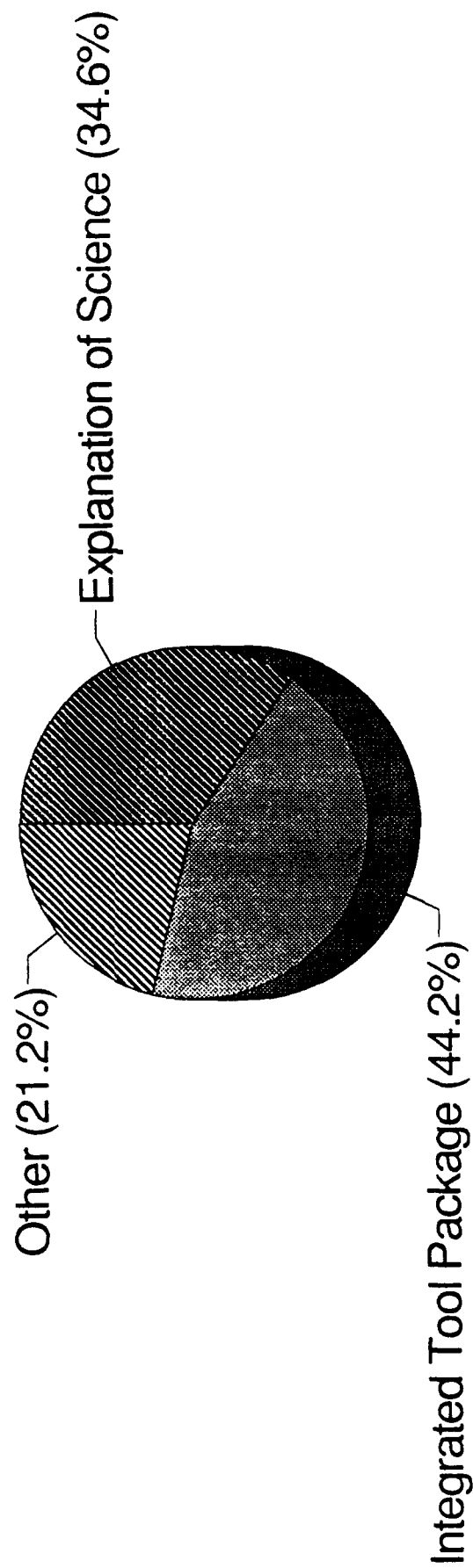


FIGURE 37

**APPENDIX A**  
**SPACECRAFT ENVIRONMENTAL INTERACTIONS**

## **SPACECRAFT ENVIRONMENTAL INTERACTIONS**

The spacecraft environment is complex and must be carefully considered during the process of spacecraft design. The spacecraft thermal balance is very different from that of earth-based systems. The design must be examined for problems with electromagnetic interference. Interaction of the spacecraft with the plasma environment and high energy particles can lead to discharges. Meteoroids, debris, ambient atomic oxygen, outgassed products, and plumes can degrade surfaces. The earth's magnetic field can affect spacecraft operations, and additional plasma and neutral interactions will occur on spacecraft with plasma sources.

### **A. Thermal Balance**

A major concern in spacecraft design is thermal analysis because many spacecraft components are affected by temperature. The behavior of electronics is often strongly dependent on temperature. The sources of heat are absorbed radiation and internal generation. Differential thermal expansion of constrained components creates stresses which can result in bending. In orbit, the only way heat can dissipate is by radiation. A balance between generation, absorption, and dissipation must be maintained for correct operation of the spacecraft.

The analysis codes TRASYS II and SINDA are used together for thermal analysis. TRASYS II defines the spacecraft geometry and calculates view factors while SINDA provides a lumped element thermal analysis.

### **B. Electromagnetic Interference**

Electromagnetic interference (EMI) of spacecraft components with each other can be a nuisance or a major problem. The EMI problems with spacecraft components are similar to those encountered in the design of any electronic system. Spacecraft tend to have lower power devices which are more easily upset than ground-based devices, and shielding is kept to a minimum to reduce system weight.

The analysis code SPICE, which solves node circuit equations, is used to evaluate the extent of electromagnetic interference in the design. The code NEC III is a wire grid modeling code which uses a method of moments technique to calculate how structures act as antennas and to evaluate crosstalk. The code IEMCAP is used to analyze electromagnetic compatibility through detailed modeling of the system elements.

## C. Spacecraft Plasma Interactions

### 1. Geosynchronous Spacecraft Charging

Spacecraft surface charging is of major concern for geosynchronous spacecraft. [Garrett, 1980] At geosynchronous altitudes the environment consists of a plasma a density of  $10^8/\text{m}^3$  and an average energy of 1 eV. During a substorm the plasma is replaced by a lower density, higher energy plasma with densities of  $10^6 - 10^7/\text{m}^3$  and average energies of 1 - 50 KeV. Under all conditions the flux of the much lighter electrons greatly exceeds that of the ions. If the collection of charge were due only to primary plasma currents, all materials would charge to negative potentials of a few times the plasma temperature. However, the impact of both primary electrons and ions on exposed surfaces causes the ejection of low energy secondary electrons into space. In sunlight, photoelectrons ejected from the surface also act as a source of positive current. Under sunlit conditions, photoemission dominates and surfaces tend to charge a few volts positively. During an ionospheric substorm, surfaces in the shade or in eclipse can charge to -10 kV (and occasionally more) before equilibrium is achieved.

Overall charging skews measurements made by particle detectors on scientific satellites as the ions are accelerated or repelled by the potential difference between the plasma and the spacecraft.

Differential charging is of more concern than overall charging because it can lead to discharges. Exterior conducting surfaces which connect to spacecraft ground are at the spacecraft ground potential. The surface charge on dielectric surfaces depends on the current from the plasma to the surface, the current from the surface to the plasma through photoemission and secondary emission, and the current from the top of the surface to spacecraft ground. Surfaces of different materials (different secondary emission properties) and surfaces with different thickness of dielectric (different electrical properties) will charge differently. Photoemission currents cause sunlit surfaces to charge differently than shaded surfaces. Electrostatic barriers can form during the charging process and affect the currents to and from surfaces and, therefore, the total charge buildup. [Mandell, et. al., 1978] If one surface charges to a large negative potential and a nearby surface does not charge significantly, a discharge can be initiated. Discharges induce transients electrical pulses which could cause upsets or failures in nearby electronic hardware. [Koons, et al 1988] Even if the electronics are well shielded, discharges can degrade spacecraft surfaces by pitting and sputtering. Degradation of thermal coatings, solar cell reflective coatings, and optical sensors all affect spacecraft operations.

During the spacecraft design process the structure and materials chosen must be examined for tendencies toward discharge. At locations where high fields can develop, alternative designs, surface coatings, and materials should be considered. Cumulative effects of surfaces at elevated potentials and multiple discharges on coatings and sensors must be considered to determine if they can be tolerated by the electronics.

The analysis codes NASCAP/GEO [Katz et al, 1977] and MATCHG were written at S-CUBED to help the spacecraft designer consider the interaction between a geosynchronous satellite and its plasma environment. NASCAP/GEO is the spacecraft surface charging model in ESABASE and is used by spacecraft design engineers in the U. S., Europe, and Japan. NASCAP/GEO calculates surface voltage and field distributions for a three-dimensional spacecraft which result from such charging. Three-dimensional calculations are necessary whenever electrostatic barriers can form. MATCHG is a one-dimensional, interactive, spacecraft-charging computer code. It is useful at the engineering trade-off study stage and as a guide to which NASCAP/GEO calculations should be executed.

## 2. Polar Orbit Spacecraft Charging

Electrons and protons from the sun, stored in the earth's magnetotail, travel along magnetic field lines and interact with the earth's atmosphere. This flow gives rise to auroral beam currents that have been observed to change the structure potential of a polar orbiting spacecraft by hundreds of volts in a matter of seconds. [Gussenhoven, et al, 1985] Larger spacecraft develop larger potentials, because the negative charge collected from the beam is proportional to the spacecraft area and the positive charge collected from the ambient plasma is space charge limited. [Parks and Katz, 1980] Particle detector measurements are skewed during these events.

To address these problems the three-dimensional analysis code POLAR [Cooke, et al, 1985] was developed at S-CUBED for the Air Force Geophysics Laboratory. POLAR is used to evaluate polar-auroral charging interactions for large space vehicles.

## 3. Low Earth Orbit High Voltage Interactions

The low earth orbit thermal plasma environment consists of a low energy plasma (temperature of 0.1 - 0.3 eV) which surrounds the earth and has densities ranging from  $10^6$  at 500 km to about  $10^3$  at 5000 km. The plasma fluctuates significantly in density and ion species. [NASA SP-8021]

The interaction of the low earth orbit plasma with spacecraft can be important when spacecraft components generate a high (greater than 50 V) voltage in the presence of the plasma. The high voltage surfaces act as probes collecting plasma particles. Ground and space experiments have shown that this interaction can result in power losses to the plasma or discharges. [Kennerud, 1974] Surfaces can build up differential voltages on the order of the applied voltage. [Katz and Mandell, 1982] The differential voltages can distort instrument measurements and, if high enough, can cause discharges.

In low earth orbit plasma, solar arrays with voltages more negative than -250 V have been observed to arc. [Snyder, 1983] S-CUBED has developed a theory which attributes these discharges to accumulation of positive charges on the surface of the solar array interconnects. [Jongeward, et al, 1985] This theory was used to design high voltage bushings which were able to sustain 40 kV during the SPEAR I rocket experiment. [Katz, et al. 1989]



Analysis models of the interactions between spacecraft and the low earth orbit thermal plasma are available. The three-dimensional CAD/CAM compatible NASCAP/LEO[Mandell et al, 1982 and Mandell et al 1989] was developed at S-CUBED under contract to NASA/LeRC.

#### 4. Electron Beam Induced Charging

Above altitudes of 300 Km, spacecraft which produce electron beams can suffer from severe spacecraft charging. Unless there is a source of plasma to reduce the buildup of charge, the overall potential of a spacecraft with an electron beam will be on the order of the beam energy. Differential charging can buildup between surfaces. This behavior was seen on the SCATHA satellite. [Cohen, et al, 1981]

#### D. **Radiation**

In polar, transfer (radiation belt regime) and geosynchronous orbits, high energy particles are of particular concern. [Vampola, 1980] The trapped radiation belts, solar flares, and cosmic rays generate particles with energies from 100 KeV to hundreds of MeV. These high energy particles can degrade spacecraft surface materials and solar arrays. The energetic particles can be deposited inside dielectrics (such as cable insulation, or on printed circuit boards) and build up an electric field interior to the dielectric. This electric field can become large enough to cause a discharge. Additionally, these particles can penetrate the spacecraft's exterior covering and interact directly with interior electronics causing single event upsets.

During the design process, the affects of these interactions must be considered and mitigating action taken if needed.

#### E. **Surface Penetration**

Meteoroids are solid particles moving through interplanetary space that originate from cometary and asteroidal sources. Densities of meteoroids have been calculated from photographic and radar observations to be between 0.16 and 4.0 gm/cm<sup>3</sup> with an accepted average value of 0.5 gm/cm<sup>3</sup>. Meteoroid velocities have been observed to range from 11 to 72 km/s with 20 km/s being the accepted average. [Cour-Palais, 1969] The debris environment generated by human activity is potentially a greater concern than the meteoroid environment since the debris in space is continually increasing. Debris particles have an average density of 2.8 gm/cm<sup>3</sup> and an average velocity of 9.0 km/sec.

Penetrations can have a three-fold effect. First, the particle penetration through the outer layer of a spacecraft produces a hole. Then a spalling damage pattern is created in the layer beneath. Finally, the second layer is now exposed and can interact with the environment.

Models of the meteor and debris environments and the extent of the expected damage during a spacecraft lifetime are incorporated within the EPSAT CAE tool. Some examples

of these are the meteoroid model, METEOR, based on NASA SP 8013 by B. G. Cour-Palais, the debris model, DEBRIS, from JPL, and the TRW code IMPACTS.

#### **F. Interaction of Spacecraft with Neutral Particles**

The neutral environment is of concern up to 1000 km as the composition changes with altitude. Molecular nitrogen is the dominant species up to altitudes of 200 km. Above 90 km, extreme ultraviolet solar radiation causes molecular oxygen to dissociate into atomic oxygen. From 200 km to 650 km, atomic oxygen is the dominant species. Above this altitude, helium becomes the dominant species.

The results of the interaction of spacecraft with the neutral environment include orbital drag, atomic oxygen surface erosion, optical glow, chemical reactions, and sputtering. Drag can result in reentry. Atomic oxygen erosion can result in complete loss of thin film materials, altered surface properties, and enhanced contamination of surfaces and sensors due to the eroded materials. UV radiation enhances the effect of atomic oxygen. [Santos-Mason, 1985] Sputtering causes surface erosion, particularly for surfaces at high voltage. The principle adverse effect of surface glow is its potential to interfere with optical sensors, while chemical reactions produce contamination and potentially corrosive substances. The TRW analysis code ALOSS predicts the mass loss of materials due to atomic oxygen attack.

#### **G. Interaction of Spacecraft with the Earth's Magnetic Field**

There are three ways a spacecraft can interact with the earth's magnetic field. First is the  $V \times B$  potential difference. On a spacecraft in low earth orbit, a potential difference of 0.25 V/m forms in the direction perpendicular to both the spacecraft velocity and the earth's magnetic field. For an instrument on the remote manipulator arm of the space shuttle, this potential difference can be 5 V, which is the ram ion energy. This perturbation has created difficulties in the interpretation of measurements made on the shuttle. [Katz and Davis, 1987] Second, the motion of the spacecraft through the magnetic field can generate plasma waves which create EMI. Third, torques can be generated by the interaction between currents circulating in the spacecraft and the Earth's magnetic field. These disturbance torques can affect the spacecraft attitude and pointing accuracy.

An environment model called MAGFIELD has been developed, and is based on the International Geomagnetic Reference Field Model, Revision 1987.

#### **H. Spacecraft Created Environments**

Spacecraft operate not only in the natural environment, but in their own environment created through outgassing, attitude control effluent, waste products and plasma sources.

##### **1. Plumes and Outgassing**

Outgassed neutrals, waste products and attitude control effluent can generate optical glow, chemical reactions, and sputtering. The interaction with the released gases can be

more dramatic than the interaction with the natural neutral environment, because the densities created are higher and different species are created. The emitted gases can also be more corrosive than that of the ambient environment. Neutrals emitted by a high voltage spacecraft can be ionized, generating glow as well as acting as a plasma source.(see below)

The code SOCRATES (Shuttle Orbiter Contamination Representation Accounting for Transiently Emitted Species) developed by the Geophysics Laboratory and Spectral Sciences uses a Monte Carlo technique to examine the contamination problem for the space shuttle environment. The code uses modules for each gas source so that with minor modifications it can be applied to other spacecraft easily. Gas dynamics, complex chemistry, and photochemistry can all be included in calculations. Within the attitude control jets, chemical reactions take place which generate molecular contaminants which can degrade surfaces. Analysis codes to describe nozzle effluent are under development at S-CUBED as part of the EPSAT CAE tool development.

## 2. Plasma Sources

Plasma sources have been proposed to control the potential of spacecraft and reduce both overall and differential charging. A plasma cloud around a spacecraft facilitates the motion of charged particles between the ambient plasma and the spacecraft. On a high voltage spacecraft in low earth orbit, a neutral gas source can act as a plasma source. When a spacecraft is releasing neutral gas at potentials of at least tens of volts positive, electrons are attracted from the surrounding plasma. Under typical low earth orbit conditions, the attracted electrons will ionize the neutral gas released, and this plasma cloud will act the same as a deliberately generated one. This effect was seen on the Charge II rocket flight. [Myers, et al, 1989] Plasma sources can also produce contamination, chemical reactions, and sputtering, particularly for high voltage systems.

A model of plasma sources is being incorporated into the S-CUBED developed NASCAP/LEO.

**APPENDIX B**  
**CAE SURVEY QUESTIONNAIRE**

**SPACECRAFT DESIGN**

**CAD/CAM/CAE**

**SURVEY**

**I. PERSONAL INFORMATION (Optional)**

If you would like your name added to our address list for future communication on this subject, please indicate by filling in the requested information below:

Name \_\_\_\_\_

Company \_\_\_\_\_

Division/Mail Stop \_\_\_\_\_

Street \_\_\_\_\_

City/State \_\_\_\_\_

Zip Code \_\_\_\_\_

Phone (\_\_\_\_\_) \_\_\_\_\_ - \_\_\_\_\_

E-Mail address \_\_\_\_\_

What best describes your job function?

- ☐ Project Management  
☐ Design/Development  
☐ Quality and Test  
☐ Research and Development  
☐ Systems, MIS, and Software  
☐ Other, (please specify) \_\_\_\_\_

Do you wish to receive a copy of the survey results? ☐ Yes ☐ No

**II. HOW DO YOU FEEL ABOUT ADDRESSING ENVIRONMENT FACTORS EARLY IN THE SATELLITE DESIGN PHASE?**

Must Be Done!	Should Be Done	Do It If Convenient	Not Worthwhile
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**III. WHAT FACTORS ARE WEIGHED TO CHOOSE A CAE TOOL OR SYSTEM ANALYSIS PROGRAM? (Rank from 1-6 with 6 being the most important.)**

	6	5	4	3	2	1
Price	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Product Support	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Application Assistance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Computer Platform	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Capability	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Documentation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

#### IV. CAE TOOLS/SYSTEM ANALYSIS PROGRAMS

##### A. Which Programs are Used?

Commercial Analysis Programs (acquired from sources other than your company)

Which COMMERCIAL programs (e.g. SINDA, SPICE, NASCAP, POLAR, etc.) are used at your facility to perform the following analysis functions?  
Please enter a program name next to all that apply.

Thermal \_\_\_\_\_  
EMC/EMI \_\_\_\_\_  
Spacecraft Charging \_\_\_\_\_  
Surface Chemistry \_\_\_\_\_  
Debris Impingement \_\_\_\_\_  
Radiation Dosage \_\_\_\_\_  
Mechanical (Stress/Vibration) \_\_\_\_\_  
Other (Specify) \_\_\_\_\_  
\_\_\_\_\_

Are any IN-HOUSE programs used for the following analyses? If so, place the name of the program next to the appropriate analysis function.

Thermal \_\_\_\_\_  
EMC/EMI \_\_\_\_\_  
Spacecraft Charging \_\_\_\_\_  
Surface Chemistry \_\_\_\_\_  
Debris Impingement \_\_\_\_\_  
Radiation Dosage \_\_\_\_\_  
Mechanical (Stress/Vibration) \_\_\_\_\_  
Other (Specify) \_\_\_\_\_  
\_\_\_\_\_

**AFTER FILLING IN PROGRAM NAMES**

**AT LEFT, PLEASE TURN THIS**

**PAGE TO BEGIN SURVEY**



**B. Questions About the Programs.**

1. Does it work with one-, two-, or three-dimensional models?

	1-D	2-D	3-D	Time Dependent
-----	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
-----	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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2. Does it accept objects defined  
using standard CAD/CAM formats?

Yes

No

<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>
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PLEASE TURN THIS PAGE  
TO CONTINUE SURVEY

3. Is graphics output available?

Yes

No

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

4. Can the program provide input for  
standard post-processing packages?  
Like what?

Yes

No

☐☐

PLEASE TURN THIS PAGE  
TO CONTINUE SURVEY

**C. General Questions**

1. What level of training/education do people who perform the analyses have?

none    B.S.    M.S/  
                                 M.A    PhD    special

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

1

2

**TO CONTINUE SURVEY**

3. At what point in the design process are the CAE Software Analysis tools currently used? (Please mark all that apply.)

[illegible]

**PLEASE TURN THIS PAGE TO  
BEGIN SECTION V**

**V. COMMERCIAL CAD/CAM SOFTWARE**

**A. What commercial CAD/CAM software (e.g., PATRAN, I-DEAS, etc.) is currently available to the spacecraft designer at your facility?**

	Yes	No
Mechanical Design _____	<input type="checkbox"/>	<input type="checkbox"/>
Circuit Design _____	<input type="checkbox"/>	<input type="checkbox"/>
Printed Circuit Board Design _____	<input type="checkbox"/>	<input type="checkbox"/>
Configuration Control _____	<input type="checkbox"/>	<input type="checkbox"/>
Other _____	<input type="checkbox"/>	<input type="checkbox"/>
Other _____	<input type="checkbox"/>	<input type="checkbox"/>
Other _____	<input type="checkbox"/>	<input type="checkbox"/>
Other _____	<input type="checkbox"/>	<input type="checkbox"/>

**B. What in-house-developed CAD/CAM software is currently available to the spacecraft designer? (cite specific examples)**

Program Name	Function		
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
_____	_____	<input type="checkbox"/>	<input type="checkbox"/>

**C. Can the in-house-developed CAD/CAM software exchange data with any commercial CAD/CAM software packages? If so, which ones?**

Yes	No
<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>



**D. What standard format output files are produced by CAD/CAM programs used?**

IGES PHIGS DXF TWGES None

-----	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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-----	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**VI. PLEASE TELL US WHAT CAE TOOLS YOU ARE AWARE OF, BUT DO NOT USE? SOME GOOD REASONS ARE:**

Generally unavailable; too expensive to acquire; too expensive to learn;  
too difficult to use; program approval required; not validated; inappropriate/  
nonexistent model(s); hardware incompatibility; slow execution time; too many  
"bugs" maintenance intensive; cheaper to subcontract; don't know enough about;  
other (please specify).

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

## VII. COMPUTING ENVIRONMENT

A. What kind of computer environment do you now have? (fill-in all that apply)

### HARDWARE:

VAX ☐

Cray ☐

Sun ☐

Apollo ☐

Other ☐ (specify) \_\_\_\_\_

### NETWORK ACCESS: (check all that apply)

SPAN ☐

Internet ☐

TCP/IP ☐

DECNET ☐

Other ☐ (specify) \_\_\_\_\_

### OPERATING SYSTEM: (Please fill in version number if you know it.)

☐ UNIX

☐ VMS

☐ MS-DOS

☐ Other

### GRAPHICS CAPABILITY (2-D, 3-D, color, etc.): (Mark all that apply.)

	2-D	3-D	Color	Rotation	Co-ordinate Transformation
Terminal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Software	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## VIII. FUTURE CAE TOOL DEVELOPMENT

**A. How useful do you consider the following potential improvements in future CAE tool development.**

1. CAD/CAM modeler combined with an environmental analysis tool. This would allow the analysis code to use the same physical model as the CAD/CAM code.

Very Important ☐ Important ☐ Not Important ☐

2. 386i or workstation-based tool back-of-the-envelope spreadsheet type program.

Very Important ☐ Important ☐ Not Important ☐

3. A user-friendly screen-oriented front end tailored to a specific analysis code.

Very Important ☐ Important ☐ Not Important ☐

**B. What environmental interaction analysis programs should be incorporated in CAE tools?**

1. \_\_\_\_\_  
2. \_\_\_\_\_  
3. \_\_\_\_\_  
4. \_\_\_\_\_

**C. What kind of programs or design tools do you wish you had to make the spacecraft design process simpler, faster, cheaper, better?**

1. \_\_\_\_\_  
2. \_\_\_\_\_  
3. \_\_\_\_\_  
4. \_\_\_\_\_

**D. Do you think it is important that an integrated CAE tool package in which all the analyses can be performed should be available?**

Very Important	Important	Not So Important	Not At All Important
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**E. What CAE aids would you like to see developed? (Check out all that apply.)**

- ☐ Concise explanation of the science.
- ☐ Integrated tool package.
- ☐ Other tool (specify)\_\_\_\_\_.
- ☐ Other tool (specify)\_\_\_\_\_.
- ☐ Other tool (specify)\_\_\_\_\_.
- ☐ Other tool (specify)\_\_\_\_\_.
- ☐ Other tool (specify)\_\_\_\_\_.

**F. Additional Comments**

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**APPENDIX C**  
**KEY EXPERT LIST**

RICHARD ACKER  
NASA/MSFC  
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35812

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SSD/WE  
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GEORGE J. BERZINS  
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LANL  
LOS ALAMOS, NM  
87545-0000

BERNIE BLAKE  
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P.O. BOX 92957  
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90009-2957

FREDERICK P. BLAU  
ROCKETDYNE, A-38  
6633 CANOGA AVE.  
CANOGA PARK, CA  
91303-0000



ALEXANDER BOGORAD  
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JOE BOROVSKY  
MAIL STOP D-438  
LOS ALAMOS NATIONAL LAB  
LOS ALAMOS, NM  
87545-0000

JEFF BROWN  
NASA/MSFC  
M/S EB34  
HUNTSVILLE, AL  
35812

KRISTIN BRUNO  
JPL  
M/S 125-233  
4800 OAK GROVE DRIVE  
PASADENA, CA  
91109

GEORGE R. CARIGNAN  
UNIVERSITY OF MICHIGAN  
2306 EECS  
ANN ARBOR, MI  
48109-2116

RALPH CARRUTH  
MAIL CODE EH-12  
NASA/MSFC  
HUNTSVILLE, AL  
35812-0000

TOM CAYTON  
MAIL STOP D-438  
LOS ALAMOS NATIONAL LAB  
LOS ALAMOS, NM  
87545-0000

E. CHAN  
LOCKHEED  
MC R21G-1  
600 GEMINI AVE.  
HOUSTON, TX  
77058-0000

HERB A. COHEN  
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**APPENDIX D**

**EVALUATION CRITERIA FOR ESABASE CRITIQUE**

## EVALUATION CRITERIA FOR ESABASE CRITIQUE

The statement of work in Section 9 calls for a critique of the ESABASE software as an integrating tool; therefore the critique will focus on how well ESABASE unifies various spacecraft design analysis codes. The goal of this critique is to determine the strengths and weaknesses of the ESABASE software package.

The major concern when evaluating any computer software is: does it do the appropriate task? ESABASE provides a framework, an object generating module, analysis modules, environment modules, user interfaces, a data base, and interfaces to other codes. ESABASE has the components needed for an integrating CAE tool for spacecraft design. Specific criteria to determine how well ESABASE fills the needs of the spacecraft design community are discussed below.

### A. SPECIFIC CRITERIA

#### 1. Cost, Availability, and Resources Needed

The first criteria to be considered when evaluating any computer software is the cost of purchase or lease and availability. The cost of maintenance and revisions must also be considered. The cost of installation, including the time of any computer services staff, is part of the cost of purchase. ESABASE is available for the purpose of space research to any European company from the contracts office at ESTEC. There is no charge for its use. Non-European industrial and government organizations must contact the international affairs office. At present the only U. S. installation of ESABASE is at the Goddard Space Flight Center.

The next class of criteria are hardware, operating system, and portability considerations. Which computers is the software available for? Which graphics devices are needed/can be used? Is any special equipment such as tablets or special keyboards required? How much disk space is needed for the executables and accompanying source code? The cost and availability of the appropriate hardware are important considerations in the evaluation of any software package.

ESABASE is only available on VAX computers with the VMS operating system. While VAXs historically have been widely used machines, the VMS operating system is proprietary. This limitation increases the cost of use of the code. ESABASE graphics work best with Tektronix terminals such as the 4105 or 4207. It can also output PostScript graphics. No special keyboards or tablets are needed. Only the ESABASE executable is distributed and it takes 20,000 blocks (10 Megabytes) of disk space.

Of course, the disk space needed to usefully execute a complex analysis problem is not only the size of the executable files, but also the space needed for data, graphics, and other files connected with the specific problem. The disk space needed will be assessed by asking users and by looking at the disk space needed for the sample problems described below.

## 2. Ease of Use

The time it takes a new user to learn to use the tool is often the deciding factor in the success or failure of a CAE tool. Software which is difficult to learn is often resisted by the engineering community. Some of the factors which affect the training time are availability and cost of training classes and manuals, sophistication needed to use the software, and similarity to other software with which the user is already familiar.

The amount of time needed to obtain analysis results from the CAE tool is another important consideration. At each stage of an analysis, the time of the engineer who does the calculation, the computer time used during the calculation, and the time during which the engineer must wait for results are all important. The first stage of analysis is geometry definition. ESABASE has its own geometry definition package which can be used for the system description in most of the ESABASE analysis codes. ESABASE can also translate input from some external geometry packages such as EUCLID and PATRAN II. Once the geometry has been defined, it is stored in a database. If all of the analysis codes use the same geometry definition, this stage is only needed once. The second stage of analysis is the set-up and execution of a specific analysis problem. The time needed for the analysis code itself to be executed will not be considered as this task is to evaluate ESABASE as an integrating CAE tool. The final stage of an analysis is the interpretation of results. CAE tools can greatly ease this process by presenting graphical information of surface values, plane slices, or specific points.

The major advantages gained with the use of an integrating CAE tool are 1) that the engineer only needs to learn to use one user interface and 2) that information can be transferred from one analysis code to another.

ESABASE Gateway provides for transfer of data from an ESABASE data file to external programs which have more extensive post-processing capabilities. Some of the packages supported are MOVIE.BYU, PATRAN II, EUCLID, CAD3D, CYBERMATE, RASTER, MODEL, PREVIEW, SUPERTAB, and GEOMOD. ESABASE can also output IGES format files. Any additional packages with which ESABASE can interface will be noted.

## 3. Maintenance

Another important consideration in software evaluation is how difficult the software is to maintain. With respect to an integrating CAE tool this includes the effort required to change one part of the tool or to add (or replace) an analysis model.

**APPENDIX E**

**VERBATIM COMMENTS FROM RESPONDENTS**

## VERBATIM COMMENTS FROM RESPONDENTS

### VI. PLEASE TELL US WHAT CAE TOOLS YOU ARE AWARE OF, BUT DO NOT USE?

1. I-DEAS Not available.
2. Would like more information on what is available for electrical design and documentation.
3. All are too expensive to learn!!!
4. Mainframe Finite Element Programs (e.g. NASTEAN) too difficult to use, too expensive
5. Finite Element Heat Transfer - most space applications require finite difference models for commonality
6. I-DEAS - too expensive; COSMOS - not quite capable enough; VersaCad, AutoDesk, etc. - inappropriate.
7. General lack of awareness of what is in the community.
8. Lack of desire to pay for initial and continuing fees.
9. Desire to continually make our own modifications/upgrades to the software.
10. In-house expertise to do the job.
11. Procurement (government) procedures are daunting.
12. MSC/EMAS - Electromagnetic Analysis System - too expensive
13. Integrated Engineering Software - too expensive
14. Ansoft/Maxwell EM Analysis software - too expensive
15. I-DEAS - not enough knowledge
16. Design View - too expensive

## VIII. FUTURE CAE TOOL DEVELOPMENT

### B. What environmental interaction analysis programs should be incorporated in CAE tools?

1. Easy UNIX to MS-DOS conversion.
2. Thermal
3. Radiation (Total does at chip level).
4. Weight & CG
5. Mechanical resonance
6. High quality translators.
7. Thermal
8. Circuit analysis
9. Simulation of end-to-end electrical systems.
10. Stress
11. Thermal
12. Materials
13. Everything!!!!
14. Contamination (CONTAM, MULFLUX or equivalent).
15. Plasma interactions (LEO, NASCAP)
16. Surface degradation
17. SEU analysis
18. Plasma density
19. Neutral species
20. Meteor/debris
21. Solar & trapped radiation
22. Oxygen erosion
23. NASCAP POLAR
25. CONTAM or equivalent
26. Standard environment models (
27. Quick running codes
28. ISEM and ISEM update for neutral emissions/ions/ion emission/charge density, bulk currents and light.
29. Kessler model
30. AE8, AP8
31. Neutral atmosphere - MET, MSIS, Earth GRAM
32. Floating potentials
33. Arcing
34. Atomic oxygen
35. Sputtering
36. Debris
37. Thruster Plumes
38. RAM/Wake
39. EMI-Plasma
40. S/C Charging with EMC/EMI
41. Surface chemistry with S/C Charging and thermal

42. Calculate plasma density/constituent contours
43. As many as possible
44. Random vibration
45. Thermal
46. Linear/Non-linear stress
47. NASCAP
48. SPICE
49. All codes should be converted to interface with CAD/CAM - i.e., take  
objected from CAD/CAM all codes should store data and output data in  
a transparent way so interfaces between codes post processor

**C. What kind of programs or design tools do you wish you had to make the spacecraft design process simpler, faster, cheaper, better?**

1. More workstation hard disk storage.
2. Center of gravity analyses.
3. Radiation (total dose)/SEU simulator.
4. Color graphical thermal simulator.
5. RAD
6. Workstation based analysis programs.
7. Integrated thermal analysis for electronics packaging.
8. Electronics design with integrated thermal analysis.
9. Standardization of operation between operation systems.
10. Mechanisms simulation
11. Integrated 3-D analysis tool.
12. Rapid 1-D analysis tool.
13. Interactive 3-D object definition.
14. Better CAD/CAE interface
15. post-processor using standard input
16. Translator from finite element to finite difference (thermal)
17. A PC version of TRASYS that's easy to use.
18. Better CAD tool (being developed in-house)
19. Codes with standard handles and standard user interfaces rather than a  
different one for each code.

**F. Additional Comments**

- A workstation should be available to the engineer which provides the  
CAD/CAM, analysis, programming, pre-and post-processing, and word  
processing capabilities at one workstation. That is to include a personal  
computer availability along with the analysis capability.
- Use MacIntosh for low cost, ease of use, read accessibility, and low  
training cost. Wide range of software available.



- The complex gas density environment and emissions, scattering that results is very important. The surface effects of deposited contaminants should be developed that incorporates effect on transmission, reflectance, absorptance, solar absorptivity and surface conductivity from ground tests and flight data.
- This survey is too complicated to be useful.
- Our tool (SMT) is very specific to our needs. A utility which would help users convert to "standard" input/output formats would be helpful.
- SMT is government-owned and will be releasable to anyone once documentation is complete. Anyone willing to assist in the documentation process will be cordially received.
- SMT currently is SUN specific and requires PHIGS. Anyone willing to participate in a conversion process to X-windows is welcome!